AFFDL-TR-79-3080,VOL.I

LEVEL

TOTAL AIRCREW WORKLOAD STUDY FOR THE AMST VOLUME I, RESULTS

THE BUNKER RAMO CORPORATION
ELECTRONIC SYSTEMS DIVISION
WESTLAKE VILLAGE, CALIFORNIA

FEBRUARY 1979

TECHNICAL REPORT AFFDL-TR-79-3080, VOL. I
FINAL TECHNICAL REPORT FOR PERIOD MARCH 1976 - NOVEMBER 1977

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFFDL-TR-79-3080 Vol 1	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Total Aircrew Workload Study for the AMST. Volume I. Results	5. TYPE OF REPORT & PERIOD COVERED FINAL Mar 1976-Nov 1977
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ralph P. Madero, George A. Sexton, David Gunning [redacted] Corporation; Richard Moss AFFDL/FGR	8. CONTRACT OR GRANT NUMBER(s) F33615-78C-3614
9. PERFORMING ORGANIZATION NAME AND ADDRESS AFFDL/FGR Air Force Flight Dynamics Laboratory, Wright Patterson AFB, Ohio 45433 and Bunker Ramo Corp, ESD, 4130 Linden Ave, Dayton, Ohio 45432	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2403/04/06
11. CONTROLLING OFFICE NAME AND ADDRESS Crew Systems Development Branch, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio 45433	12. [redacted] Febr[redacted]979
	13. NUMBER OF PAGES 67
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

AMST; Advanced Medium STOL Transport; STOL; Short Takeoff and Landing; Tactical Transport; Aerial Delivery; Air Drop, Air Land; Troop Drop; Combat Offload; SKE; Station Keeping; Nav Management; Integrated Communications; LAPES; Full Mission Simulation; Total Aircrew Workload; CDS; Containerized Delivery System;

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

There is a growing realization within the USAF that state of the art crew systems may allow cost effective reductions in crew complements. The present study, titled the Total Aircrew Workload Study (TAWS) addresses the minimum crew complement required and conceptually, the crew systems required to support the minimum crew of an Advanced Medium STOL Transport (AMST) in the accomplishment of the tactical transport mission. The study involved the simulation of a total tactical airlift mission which was flown by operational

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19. (continued) Head Up Display; Tactical Airlift; Timing Task; Crew Complement Study; Loadmaster; Army Logistic Support.

20. (continued) (C-130) tactical airlift aircrews in order to further refine crew complement and crew system concepts established in earlier mockup studies. The results of this study indicate that two pilots, a loadmaster and a crew chief type additional crew member can fly the total AMST mission if provided with adequate state of the art crew system capabilities, as identified in this report.

The report is presented in two volumes. Volume I describes the TAWS program and presents the results. Volume II presents a detailed description of the navigation and communication system used during the TAWS evaluation.

FOREWORD

This report documents the Total Aircrew Workload Study which addresses the issues of minimum crew complement and crew system capabilities required for the accomplishment of the tactical transport mission with an Advanced Medium STOL Transport (AMST) aircraft. The study was performed with operational (C-130) aircrews in a total mission simulation environment.

This document is Volume I of two volumes. The information provided herein describes how the study was performed and the study results. Volume II presents a detailed description of the navigation and communication system evaluated during the study.

Work was conducted under Project 6190, "Control-Display for Air Force Aircraft and Aerospace Vehicles" which is managed by the Crew Systems Integration Branch; mission simulation was synthesized by the Control Synthesis Branch, Flight Control Division, Air Force Flight Dynamics Laboratory (AFFDL/FGR), Wright-Patterson AFB, Ohio.

The report was prepared in part by the off-site Human Factors Group, located at 4130 Linden Avenue, Dayton, Ohio, Electronic Systems Division, Bunker Ramo Corporation, Westlake Village, California under USAF Contract No. F33615-78C-3614.

The authors wish to acknowledge the invaluable contribution of: the AFFDL Flight Engineering Group effort headed by Captain D. Hart and Ms. K. Adams with engineering support from Mr. D. Lair, Capt. W. Cashman and Mr. S. Finch; the systems engineering design and fabrication efforts of Mr. T. Molnar and Mr. J. Kozina; the Lear Siegler simulation maintenance support headed by Mr. J. Bean; the EAI computer systems support; and the administrative support of Ms. S. Dickey.

The findings and recommendations presented are based upon experience, research, paper evaluation of aircraft systems and avionics, informal evaluation of equipment installed in a variety of aircraft, and subjective and objective data obtained through structured cockpit evaluations performed by operational aircrews in mockup and flight simulation environemnts. This approach is limited in that the effect of fatigue and the mental stress present in actual airlift operations were not simulated and do not influence the findings. Further validation and a greater degree of decision confidence can be achieved through additional simulation and/or flight test. Additionally, requirements addressed in this document may change throughout the evolution of the aircraft due to changes in user needs and capabilities, addition/deletion of unique mission requirements, advancement in technology in areas of concern, better definition of peculiar or specific equipment determined through additional research and evaluation, or other changes.

The research effort documented herein was performed between March 1976 and November 1977.

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LIST OF ABBREVIATIONS

ADF	Automatic Direction Finder
ADI	Attitude Director Indicator
ADS	Automatic Delivery System
AFCS	Automatic Flight Control System
AFFDL	Air Force Flight Dynamics Laboratory
AIC	Audio Interphone Control
ALT	Altimeter
AMST	Advanced Medium STOL Transport
AOA	Angle of Attack
APU	Auxiliary Power Unit
ASD	Aeronautical Systems Division
BDS	Bulk Data Storage
BSB	Bank Steering Bar
CARP	Computed Air Release Point
CDS	Containerized Delivery System
CDU	Control Display Unit
CRT	Cathode Ray Tube
CTOL	Conventional Takeoff and Landing
DFT	Drift
DVST	Direct View Storage Tube
DZ	Drop Zone
ECM	Electronic Counter Measures
FCI	Flight Command Indicator
FM	Frequency Modulated
FPA	Flight Path Angle
G	Gravity
GMT	Greenwich Mean Time
GS	Ground Speed
HF	High Frequency
HSI	Horizontal Situation Indicator
ICN	Integrated Communication/Navigation
IFF	Identification Friend or Foe

IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
IP	Initial Point
LAPES	Low Altitude Parachute Extraction System
LED	Light Emitting Diode
MAC	Military Airlift Command
MACH	Percent of the speed of sound
MLS	Microwave Landing System
PA	Public Address
PPI	Plan Position Indicator
PSB	Pitch Steering Bar
RMI	Radio Magnetic Indicator
RNAV	Area Navigation
ROC	Required Operating Capability
SKE	Station Keeping Equipment
SPO	System Program Office
STOL	Short Takeoff and Landing
TACAN	Tactical Aerial Navigation
TAS	True Airspeed
TAWS	Total Aircrew Workload Study
TRK	Track
UHF	Ultra High Frequency
VAM	Visual Approach Monitor
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
WPT	Waypoint

SECTION I

INTRODUCTION

This report documents the results of the Total Aircrew Workload Study (TAWS), an effort conducted by the Air Force Flight Dynamics Laboratory, supporting the development of the Air Force's Advanced Medium STOL Transport (AMST).

A. Background

In 1972 the USAF initiated the Advanced Medium STOL Transport program to develop a relatively low cost, austere field capable, medium STOL transport aircraft (Ref. 1). In conjunction with this work, the Air Force Flight Dynamics Laboratory (AFFDL) conducted a series of efforts directed at the definition of crew system design criteria applicable to the new aircraft. The first of these studies, conducted in 1975, explored the feasibility of performing the tactical resupply mission with a flight deck crew of three; pilot, copilot and navigator (Ref. 2). This effort, based on mission analysis and mockup evaluations, determined that it was possible for a flight deck crew of three to complete the mission.

When the Military Airlift Command, in its revised Concept of Operations (Ref. 3) and Required Operating Capability (Ref. 4) documents, stressed that the optimum crew size for the AMST was three, consisting of pilot, copilot and loadmaster, the AFFDL undertook a second crew system criteria definition study, this one aimed at exploring the feasibility of performing the tactical resupply mission with a flight deck crew consisting of pilot and copilot (Ref. 5). The results of this second study, although based again on mockup evaluations, suggested that a two-pilot system could perform the mission. In order to verify this finding, and investigate the interface between the loadmaster and the flight deck crew, a third investigation was undertaken; the Total Aircrew Workload Study (TAWS) (Ref. 6).

TAWS is a full-mission, pilot-in-the-loop simulation effort to either verify or refine as necessary, the crew system design criteria initially developed during the second mockup study. It is integrally tied to both of the two previous studies, in that the same tactical resupply mission is used as the basis for design work, and the logical progression from the three-man mockup study to the two-man mockup study is a sensible and efficient manner for addressing the complex issues associated with designing new cockpits.

B. Overview of the Problem

Current tactical resupply missions are flown by the C 130, a rugged, 4-engine aircraft equipped with an adverse weather, aerial delivery capability, ground mapping radar, and formation flying

equipment. It is manned, typically, by a crew of five: pilot, copilot, navigator, flight engineer, and one loadmaster. All five crew members are normally required to complete mission tasks and assure mission success. Airdrop missions require two loadmasters.

According to MAC's Concept of Operations for the AMST, the new aircraft should optimally be manned by a crew of three: pilot, copilot and loadmaster. It is not possible to take either the avionics, airframe or cargo systems directly out of the C-130 and employ them effectively in the AMST. In simplistic terms, there is insufficient real estate in the AMST cockpit to accommodate C-130 hardware. More significantly, however, is the fact that even if there were sufficient space, the flight deck equipment found in the C-130 is designed for use by four crew members. Its use by two crew members is impossible; there are far too many separate functions to be performed, far too many individual components to monitor and keep track of to permit safe and reliable operation of the system. It is also suspected that the C-130 loadmaster workload and crew systems require updating if the cargo compartment crew complement is reduced to a single loadmaster, especially when considering a reduced flight deck crew.

Thus, the issue being dealt with in TAWS is to finalize design criteria for a two-pilot, one loadmaster airplane whose airdrop mission is currently being performed by a six-crew member system.

C. Overview of Technical Issues

The work accomplished during the two-man mockup study indicated that in addition to physically controlling the aircraft, there were several major mission task areas whose accomplishment was critical to mission success. These areas included navigation, communication, airdrop planning and coordination, formation position monitoring and Visual Meteorological Conditions (VMC) recovery at austere landing strips. Design criteria developed during the mockup study which addressed these areas, suggested that a useable two-pilot crew system would be characterized by a highly integrated navigation management system which would provide for planning and execution of navigation routes, aerial delivery and austere field recovery. It would also be characterized by an integrated communications system, a flight control system with some automation, a formation flying system, also with some automation and some type of visual guidance augmentation for austere strip arrivals. It was the objective of TAWS to either verify or refine these design criteria.

D. Summary of Results

The TAWS data was analyzed to resolve the major issues of crew complement and avionics capabilities. Crew complement results indicate that two pilots and one loadmaster can fly most of the TAWS tactical mission scenarios as long as malfunctions and emergencies do not occur. In the

case of certain types of aerial delivery missions or in the case of emergencies utilizing current (C-130/C-141) airdrop systems, an additional crew member is required, preferably with both crew chief and loadmaster capabilities.

The data on the loadmaster station indicate that the loadmaster requires a forward and an aft control console to manage all cargo compartment activities.

The data further indicate that the required avionics capabilities are: a navigation system with auto navigation features that are integrated with the autopilot, flight director and aerial delivery systems with all controls/displays easily accessible to both pilots; head up information for both pilots for visual augmentation during approach; and an improved and integrated communication system, easily accessible to both pilots. The results also indicate that the crew system configuration must allow either pilot to handle any required piloting task.

SECTION II

METHOD

The approach used in the TAWS program repeated the investigative process which occurred during the two previous AMST flight deck mockup studies. A four step process of 1) analysis, 2) criteria development, 3) design/development and 4) evaluation guided the studies while systematically providing information to update the criteria for the systems under evaluation.

A. Analysis

The TAWS analysis began with an evaluation of the two-man mockup mission tasks and the resulting crew systems design. The mockup study scenario (as presented in Ref. 2) was updated to reflect a crew of three, pilot, copilot, and loadmaster, which also included loadmaster tasks, loadmaster interaction with the flight deck crew and several malfunctions in the cargo compartment during the scenario missions. In addition, requirements affecting the design were taken from the AMST ROC, MAC Concept of Operation and a MAC user survey.

B. Criteria

The criteria developed for the TAWS investigation were based on the information gained during the AMST mockup studies. These criteria described the operating envelope of each crew system that the mockup data identified as a required system to perform the AMST mission with a two-pilot/one-loadmaster crew complement. In general the previous studies established the following criteria: the communications, navigation and flight control systems must be easily accessible to both pilots; all of the information previously provided by the navigator must be immediately accessible to both pilots; the pilots must be able to perform all piloting tasks (including IMC formation flying) from either seat; communication and navigation systems must accommodate worldwide operations including adverse weather aerial delivery and air land interaction with friendly forces at austere and possibly high threat locations that may be totally without airfield facilities; the loadmaster crew systems must provide for complete, one man operation in cargo compartment management.

C. Design

The crew systems design for the TAWS evaluation was guided by the criteria developed during the analysis and during the two previous mockup studies. The crew systems identified as design critical were: 1) communication, 2) navigation, 3) aerial delivery and 4) formation position keeping. Furthermore, a degree of integration of these systems was also implied by design criteria. The integrated communication/navigation system used during TAWS are described in detail in Volume II, this report. The formation position keeping designs adopted from the two-man mockup study results are presented in the two-man study report

(Ref. 5). The aerial delivery system for TAWS was designed on the basis of the criteria developed from a MAC user survey.

D. Evaluation

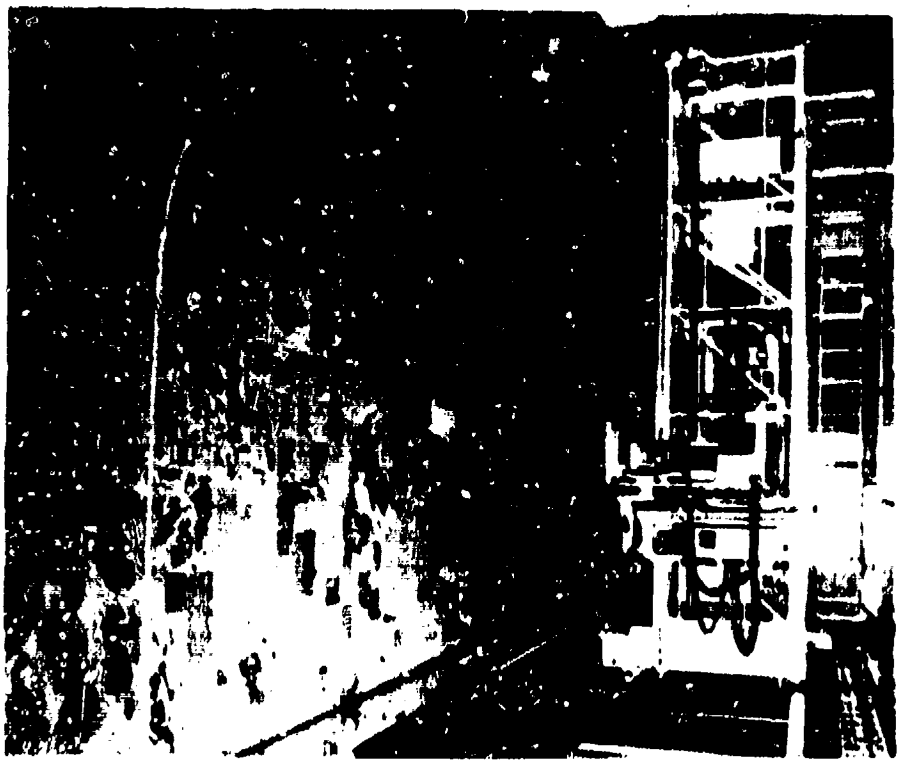
After analysis and design, a simulation evaluation was conducted. The simulator was configured with a cockpit layout responsive to the criteria. Then MAC operationally qualified crew members flew the mission scenario in the simulator in order to critique the design.

1. Simulator Fabrication and Mechanization. The development of the crew systems and supporting materials for the TAWS experiment was accomplished in several steps; a) defining the scope of the program; b) identifying available test equipment (i.e. simulation); c) selecting and developing flight deck and cargo compartment crew systems required for the TAWS experiment within the identified constraints; and d) developing a network of experimenters' stations to support the TAWS experiment.

a. Scope. The TAWS program was proposed to encompass the evaluation of representative crew system concepts to support a two pilot/one loadmaster crew complement while performing a representative tactical transport mission profile at the confidence level of in-flight simulation. The TAWS program was limited by several factors including financial constraints, time available for the development of crew systems and the physical limitations of a representative flight deck. To satisfy the TAWS objectives within the limitations of the program, a further assessment of the scenario was required. This resulted in a condensed version of the original scenario (described later in this section), retaining the most representative tasks and scenario sorties for data collection purposes.

b. Test Facility. The test bed equipment chosen for TAWS was an existing AFFDL multi-crew simulator. The aircraft model simulated for TAWS was an extensive six degree of freedom model which simulated aerodynamic control of pitch, roll, yaw, longitudinal velocity, lateral velocity, and vertical velocity, a sound system and a Redifon/Duoview visual system with two terrain boards (Figure 1). Available simulation support equipment included an environmental console which controlled the visual presentation of day, night and weather and a computer deck with multiple computer systems (Ref. 7). The flight deck was equipped with standard yoke and rudder flight controls and avionic displays including operational flight instrument panels, engine power controls/displays, flaps and spoiler controls, nose wheel steering and normal cockpit lighting controls. The crew stations on the flight deck consisted of a pilot and a copilot station (side by side) and two observer stations immediately behind the pilots. Aerodynamics and handling qualities were developed for the TAWS program to simulate a generic AMST aircraft with both STOL and conventional operating capabilities.

c. Crew System Development. The existing flight deck was modified to accept the crew systems developed for TAWS (described



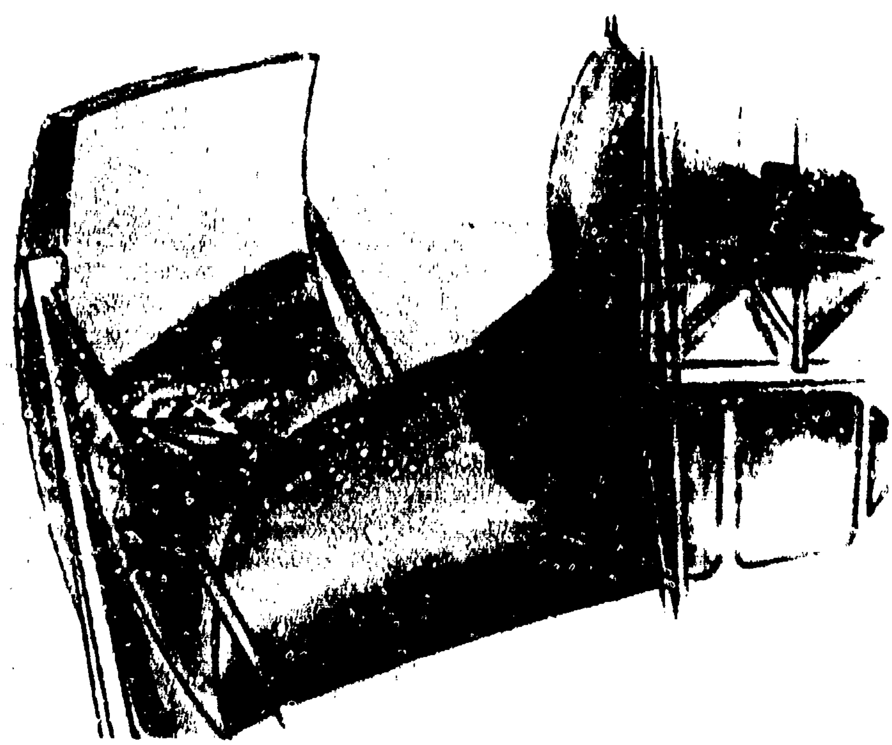


Figure 1. The Redifon Visual System for Simulation
Top Photo: Terrain Board with Camera Gantry
Bottom Photo: Duo-View Visual Projection

elsewhere in this section) by modifying the flight instrument panels, the engine instrument panels and the center console (Figure 2). TAWS crew systems included:

(1) Integrated Communication/Navigation System (Figure 3). The integrated communication/navigation system control and display consisted of five panels mounted on the center console: two voice radio transmitter selector panels with rotary selectors; an integrated communication/navigation receiver Control and Display Unit (CDU) that was equipped with tuning knobs, special purposes switches and light-emitting diodes (LED) to display selected frequency/waypoint readouts; an alphanumeric keyboard with additional special purpose keys; and a cathode ray tube (CRT) navigation/airdrop display panel containing an eight inch screen and special purpose keys.

The integrated communication/navigation CDU (Figure 4) simulated two UHFs, one VHF, one FM, and two HF communication radios. The navigaiton portion of the CDU accommodated four pilot selectable active waypoints. The CUD provided each pilot independent access to communication transmitters and receiver volume controls. Frequency selection for all communication and navigation radios was accomplished through a single keyboard or through a single set of manual tuning knobs. Navigation waypoints were selectable through keyboard only. The system provided the pilots with an active and standby frequency for each communication radio and an active and standby frequency or waypoint for each navigation radio display.

The NAV radios (TACAN, ADF, VHF/NAV) were similarly operative for all NAV aids programmed within the TAWS mission scenario area of operations. However, the voice and code identifiers were not operative. Lat/long waypoints were selectable on a world wide basis.

The navigation system, which was integrated with the pilot's flight director, the autopilot and aerial delivery system, provided the crew with the capability for automatic navigation and aerial delivery including vertical and lateral steering commands, automatic course selection, and automatic navigation radio aid/waypoint selection. The navigation system provided seven different information display pages selectable through the keyboard and displayed on the navigation cathode ray tube (CRT) (Figure 5). With the aid of the CRT and digital displays, the system displayed flight information data such as wind speed and direction, drift angle, course, track, groundspeed, vertical profile selection, vertical speed selection, time and distance to waypoint, waypoint location, nav aid location and Greenwich Mean Time (GMT). The system was capable of storing and displaying a flight plan which could be altered enroute by entering an altitude change or by entering or deleting waypoints. After the initial flight plan was entered into the nav system, the aircraft could be automatically flown throughout the entire vertical and lateral flight plan profile (with the exception of takeoff, landing and airspeed control). A complete aerial delivery mission could also be automatically navigated and flown by entering a Computed Air Release Point (CARP) into the flight plan. A detailed description of the integrated comm/nav operational concept is included in Volume II of this report.

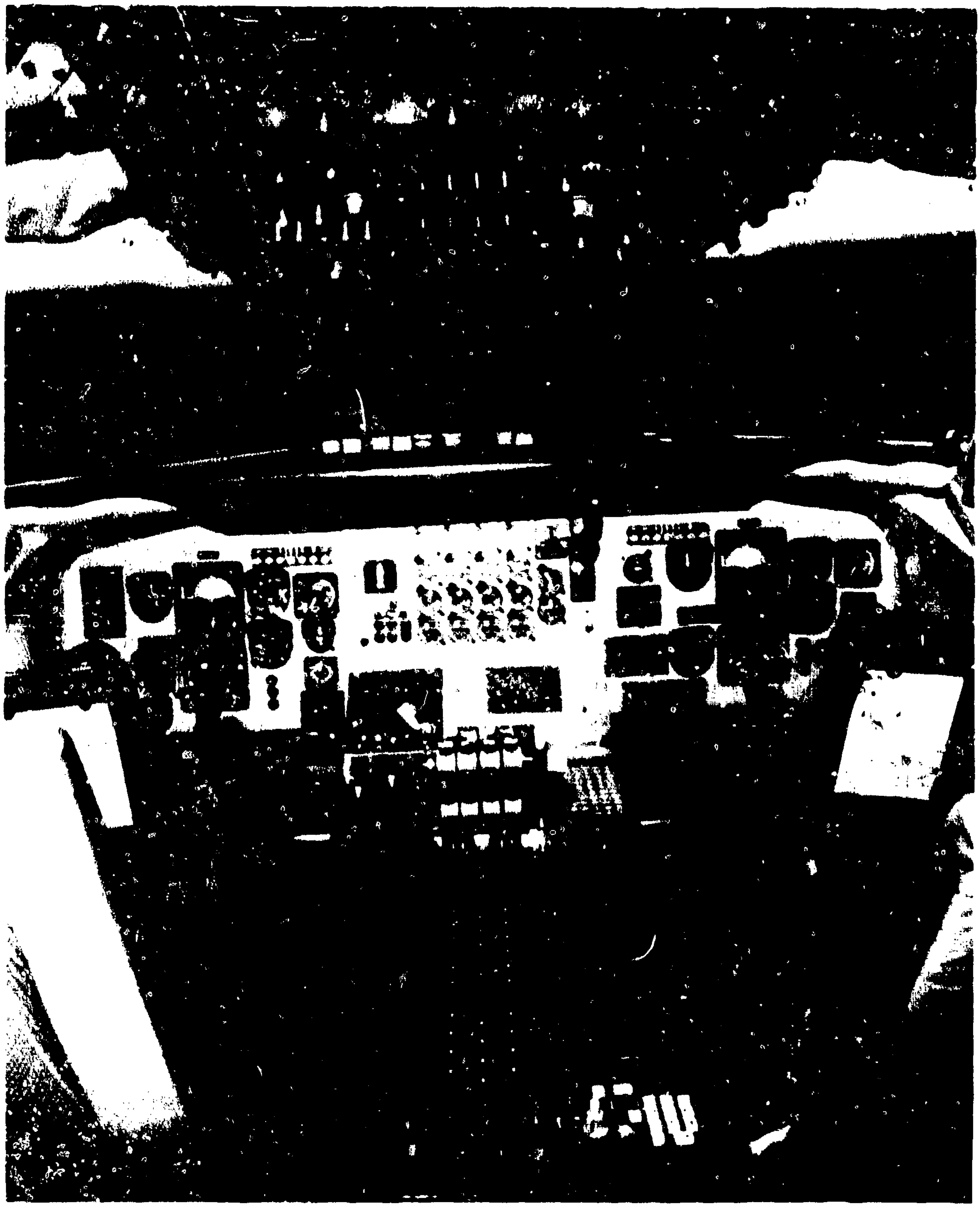


Figure 2. Flight Deck Layout for TAWS

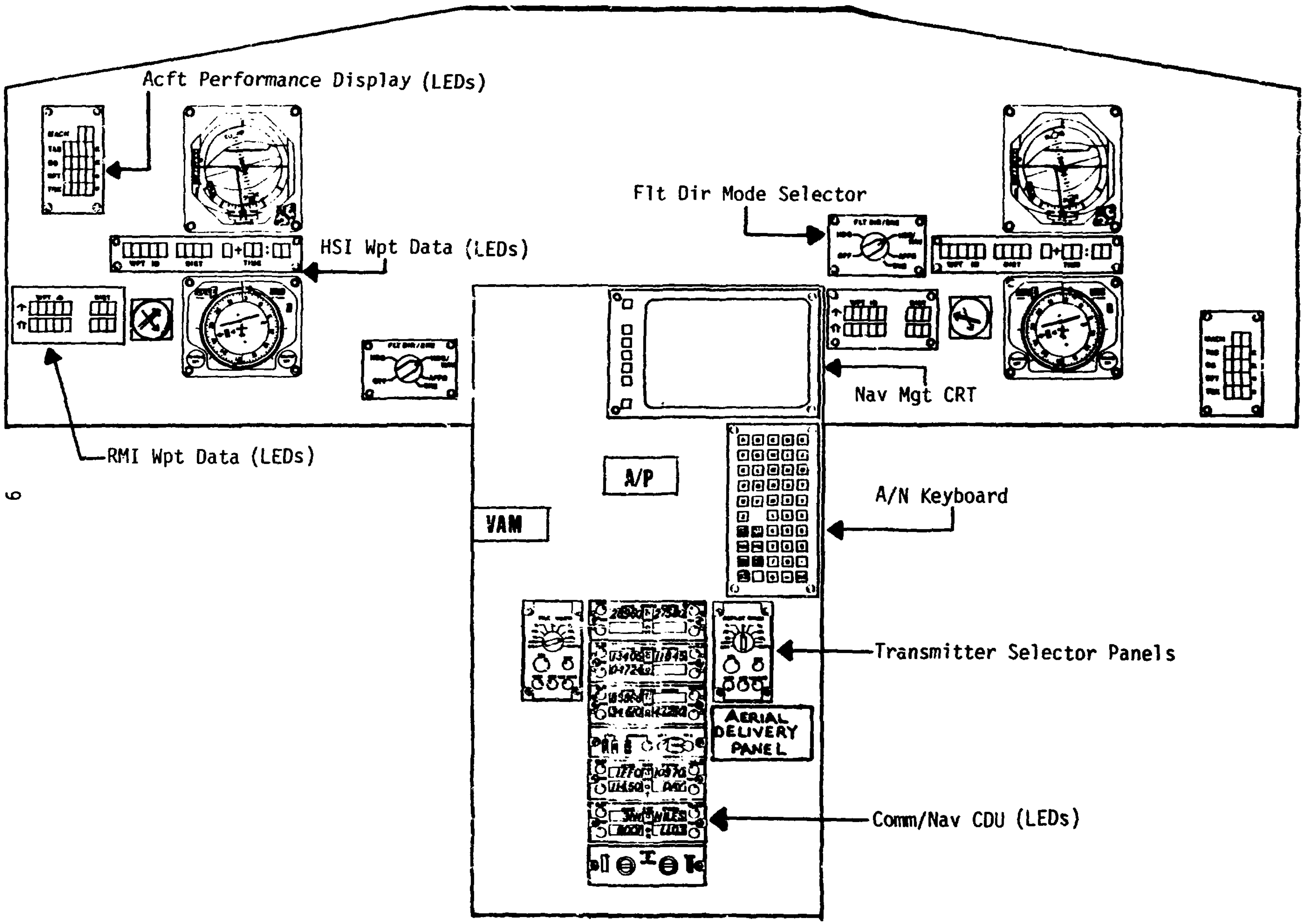


Figure 3. Control/Display Layout of Integrated Comm/Nav Systems

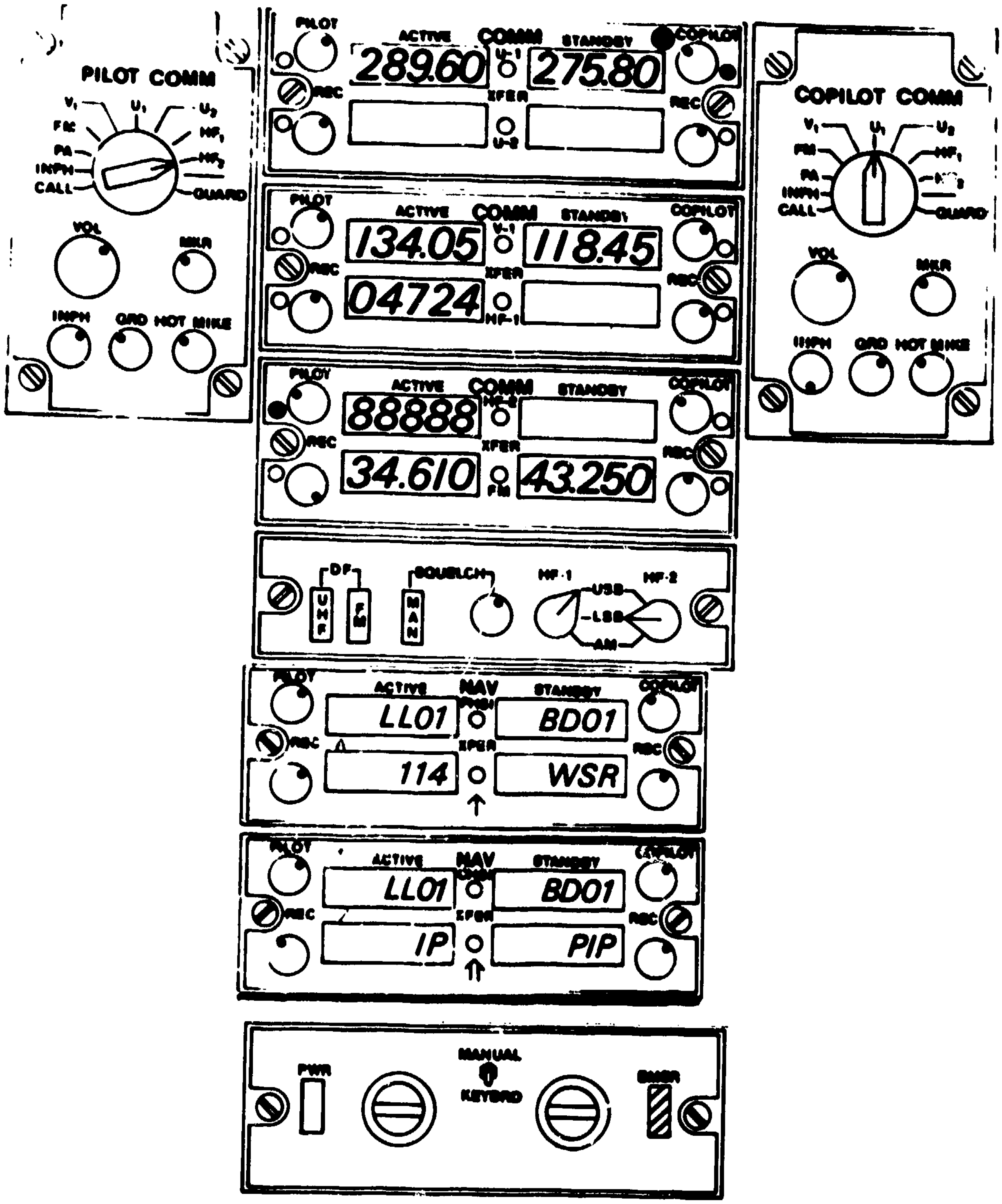


Figure 4. Integrated Comm/Nav Control Display Unit (CDU)

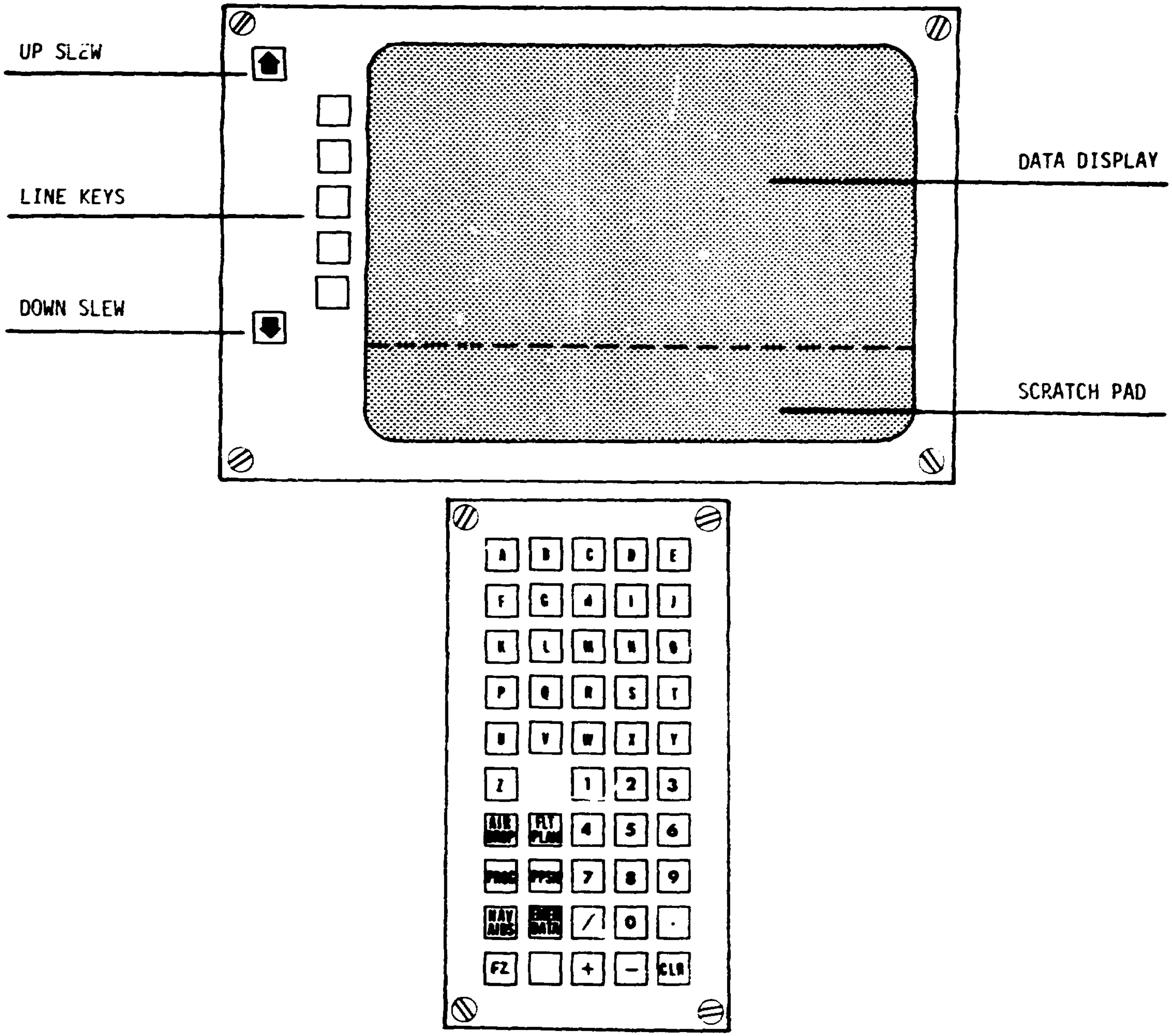


Figure 5. Nav Management Control Display Unit

(2) Flight Instrument Panel LED Displays (Figure 2 & 3). This group of six separate flight instrument panel displays provided each pilot with: nav aid/waypoint identification, time and distance information relative to each HSI display; two rows of LEDs adjacent to each RMI which displayed nav aid/waypoint identification and distance information relative to each RMI bearing pointer; and a set of LEDs on each pilot's instrument panel that displayed mach, true airspeed (TAS), groundspeed (GS), drift correction and ground track. The LEDs adjacent to the HSIs and RMIs interacted with the previously described integrated nav system.

(3) Flight Director/SKE Control Panel (Figure 6). This panel (mounted on both flight instrument panels) allowed the pilot to select the following information on his ADI (copilot's flight director mode selector was installed but was not operative): "heading" posiiton provided heading guidance on the bank steering bar (BSB); "heading/nav" position provided navigation guidance on the BSB and pitch steering bar (PSB); "approach" position provided approach guidance with increased sensitivity on the BSB only (PSB stowed). A "SKE" position was selectable but not operative for TAWS (PSB and BSB stowed). An "off" position stowed both command bars.

(4) Autopilot Selector Panel (Figure 6). The autopilot selector panel (mounted on the center console) provided the pilot the capability to couple the flight control system to hold present barometric altitude or to follow the pilot's vertical or lateral navigation guidance. Controls for approach coupling and for selecting either the pilot or copilot navigation guidance signals were installed but not operative.

(5) Ramp Door and Drop Control Panel (Figure 6). The airdrop panel, mounted on the center console, provided the pilots with ramp, cargo door and jump door control and warning lights, a static line retriever control, automatic and LAPES aerial delivery control, and personnel jump light control. The pilots' aerial delivery panel lights and controls were integrated with the loadmaster's aerial delivery panel and with the navigation management system for instrument guidance to the drop zone, including a drop system alert light that remained illuminated from the CARP leading edge to the CARP trailing edge.

(6) Visual Approach Monitor (VAM) Control Panel (Figure 6). The VAM control panel (mounted on the center console) provided flight path guidance (FPA) 2.5° thru 9° and angle-of-attack (AOA) information. The heads up VAM display (similar to a Sundstrand Corp. format) was superimposed on the visual scene and provided a fast/slow (AOA) index, FPA director bar with scale and a flare signal.

(7) SKE Flight Command Indicator (FCI) Panels (Figure 7). A functional, standard FCI control/display panel (built by the Sierra Corporation) was installed at the top of each pilot's instrument panel.

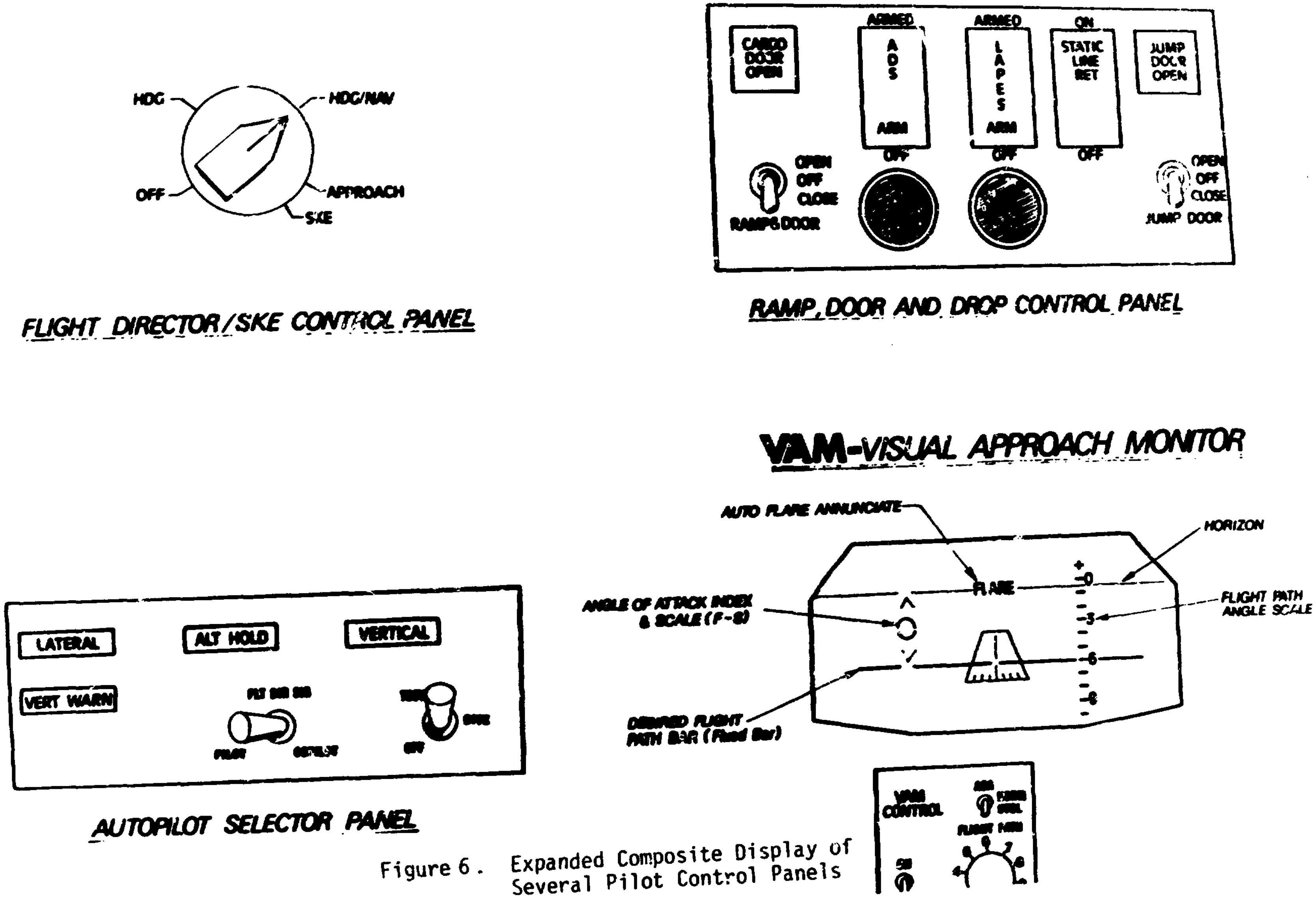


Figure 6. Expanded Composite Display of Several Pilot Control Panels

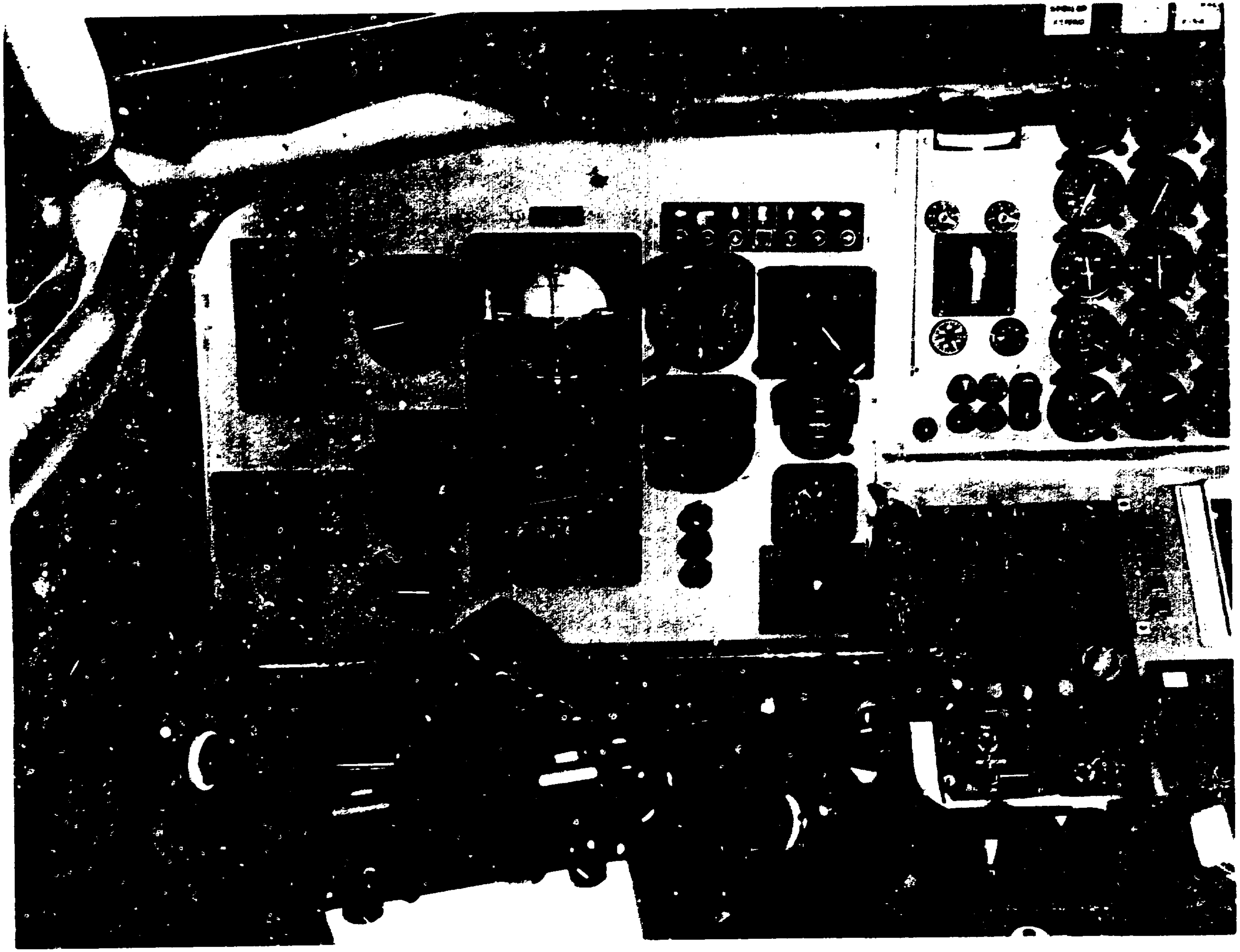


Figure 7. Pilot's Flight Instrument Panel Layout

(8) ADI and HSI Displays (Figure 7). Standard electromechanical ADI and HSI displays with some modifications were used for TAWS. Flight director information was displayed on the pilot's ADI only. The copilot's director bars were stowed. A flight path angle tape was added to the left side of both ADIs. Both HSIs appeared standard but were modified to accept automatic navigation guidance signals and ADF signals. During automatic navigation segments of flight, the course arrows and heading markers were slewed automatically by signals from the navigation system.

(9) Automatic Flight Control System Panel. A generic STOL transport flight control system and control panel were developed for TAWS simulation. The automatic flight control system (AFCS) panel (mounted on the center glare shield as shown in Figure 2) provided aerodynamic lift spoiler control and individual control of pitch, roll and yaw flight control stabilization modes. For convenience of location, fire warning lights were mounted adjacent to the AFCS controls on the control system panel.

(10) Other Functional TAWS Hardware (Figure 2). Based on cockpit mockup study results (Ref. 2, 5), it was apparent that the pilots needed devices to help control paperwork in the cockpit and IFF equipment that was easily accessible to both pilots to select IFF modes and codes. To allow evaluation of specific solutions, a standard (4096) IFF control head was installed on the pilots' center console within easy reach of both pilots. The paperwork control problem was partially addressed by installing an off-the-shelf lighted let down plate holder on each control column and by installing a lighted scroll checklist on the copilot's glare shield. The scroll checklist contained emergency checklist procedures.

Functional hardware added for criteria evaluation included pitch and roll trim indicators, master caution lights and an engine failure/fire control panel.

(11) Non-functional TAWS Hardware (Figure 2). Non-functional hardware installed for criteria evaluation included: SKE units consisting of a primary control, secondary control, range meter and radar scope; a Delco Carousel IV INS unit; hydraulic system controls; accelerometer; and a heat/anti-ice panel. Other non-functional subsystem controls were located on the overhead panel.

(12) Foam Core Control/Displays (Figure 3). The following foam core mockup controls and displays were added to the cockpit for criteria evaluation: alternate trim controls, INS mode selector, compass control, crash position indicator/recorder unit, oil and hydraulic pressure indicators, ECM panel, fuel quantity indicator, weather radar controls, antenna and X-band radar controls, and secure voice.

d. Cargo Compartment Mockup (Figure 8). The crew system issues in the cargo compartment were somewhat ill-defined in that the loadmaster requirements had to be addressed as both an unassisted single operator issue and the issue of what impact a single cargo compartment operator would have on the two-man flight deck crew. Cargo compartment crew system criteria were identified through scenario analysis, further assessments from previous mockup results and through a survey of MAC loadmasters. A cargo compartment was laid out and loadmaster consoles were designed and built. The cargo compartment mockup was austere, providing the approximate floor space for a full scale cargo compartment. The mockup included three large cargo pallets, overhead static lines and harness, a forward and aft loadmaster's control console and aircraft sound from the cab simulation system. The compartment was located in a room adjacent to the flight simulator room and was bounded on the sides by three walls and a curtain. The overhead was open except for the static lines.

(1) Forward Control Console (Figure 9). The forward loadmaster's control console provided the loadmaster with an operational communication station (AIC-18/headset), a cargo door/airdrop control panel, console lighting controls, a work table and crew seat. The cargo door/airdrop control panel interacted with the pilot's control panel and the aerial delivery portion of the navigation management system, providing alert lights for the automatic delivery system (ADS) and the low altitude parachute extraction system (LAPES), an aerial delivery alert light (red) and a drop/jump light (green). Cargo, ramp and jump door position lights, as well as aerial delivery lights and controls were also provided. Mockup foam core control/displays were mounted on the loadmaster's control console and included: hydraulic cargo system and APU controls, cargo winch controls, cargo compartment lighting and temperature controls, oxygen controls and emergency levers and controls for backup cargo release systems.

(2) Aft Control Console (Figure 10). The rear cargo compartment control console was equipped with a crew seat and duplicates of the forward console communication system, door control and aerial delivery control panel. It also contained similar mockup controls/displays for APU, oxygen, public address system (PA), cargo compartment lighting and cargo winch controls. Both loadmaster AIC-18 units provided intercom with the pilots and monitor capabilities for all flight deck communication radios.

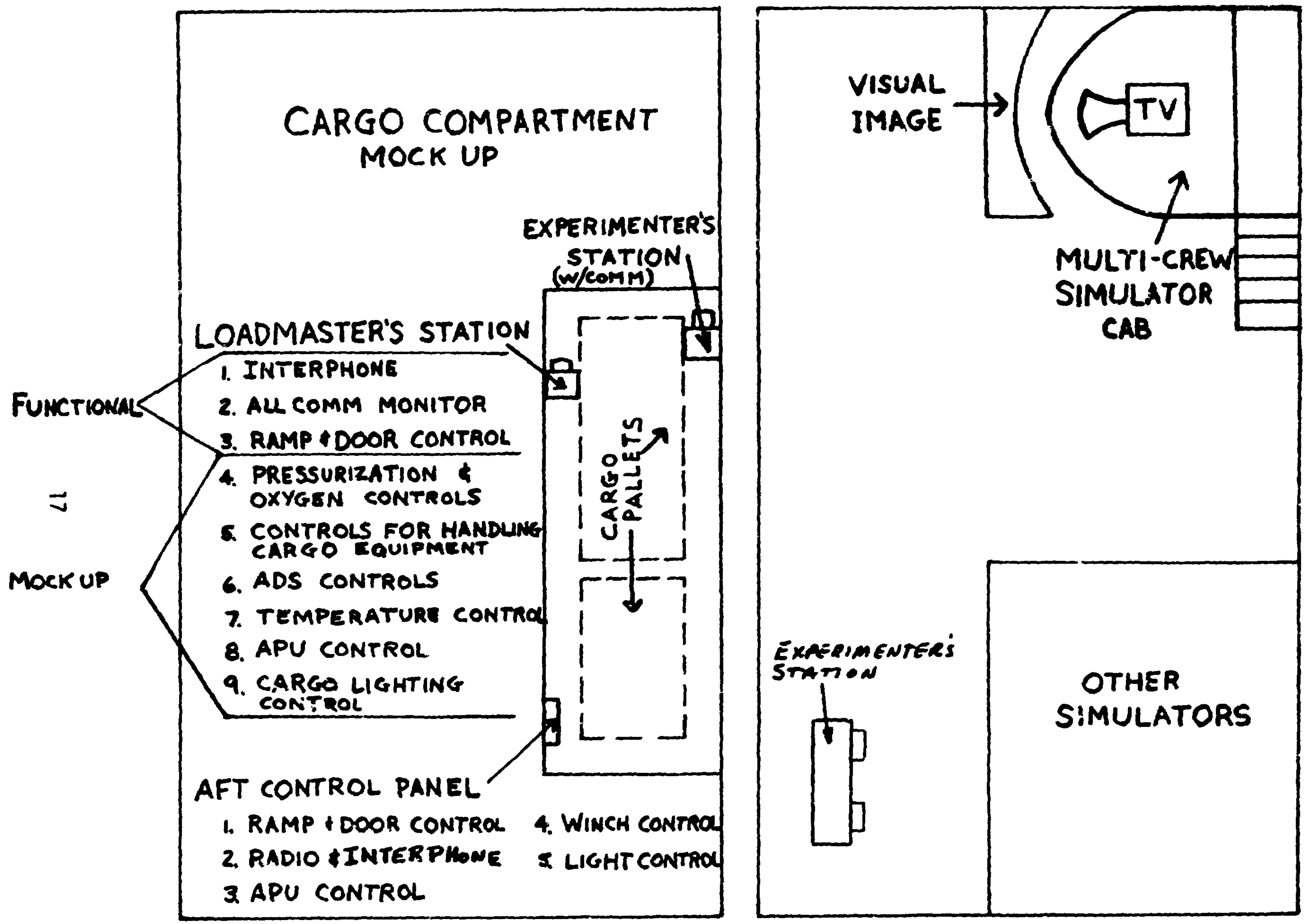


Figure 8. Cargo Compartment and Simulator Floor Plan

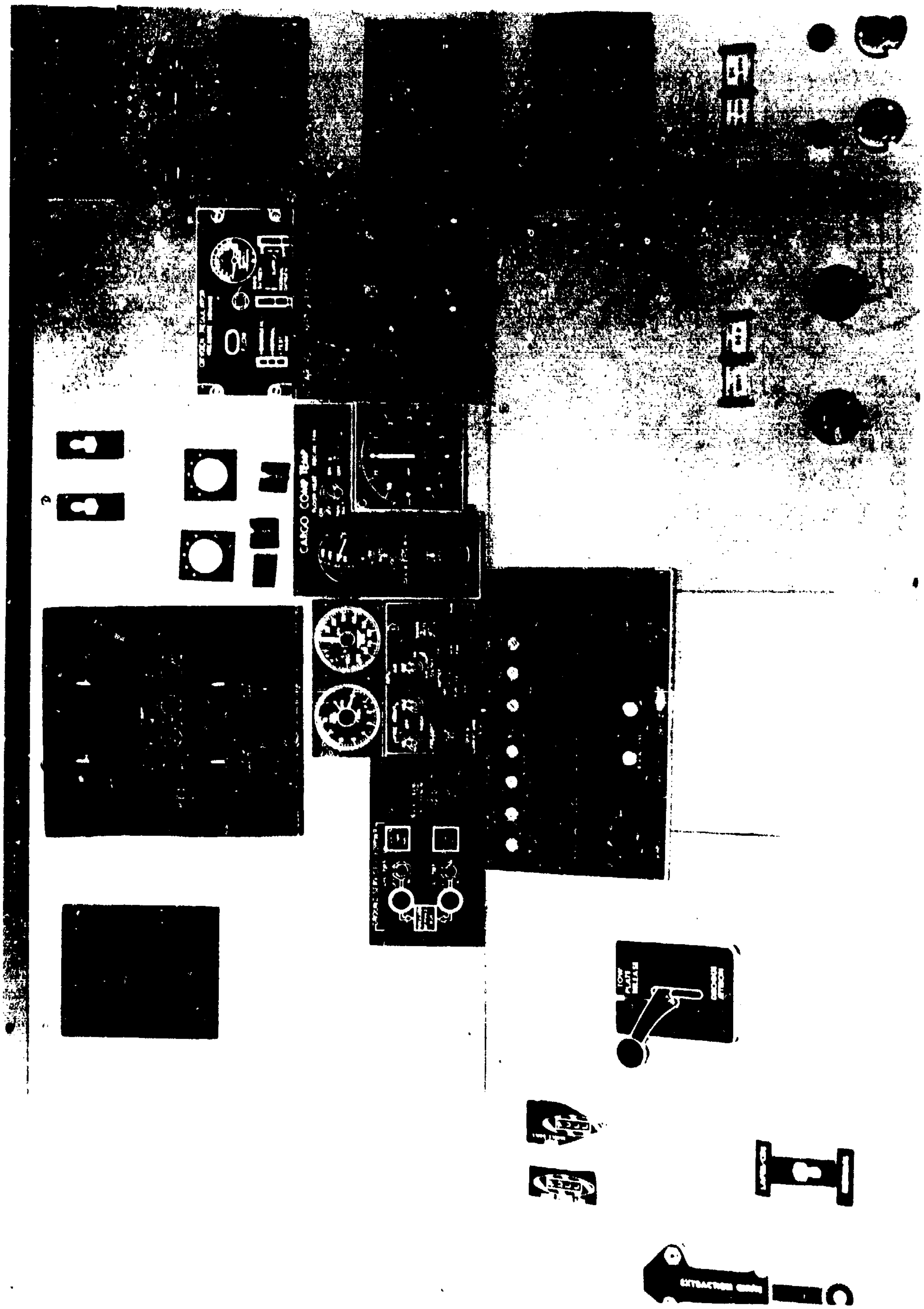
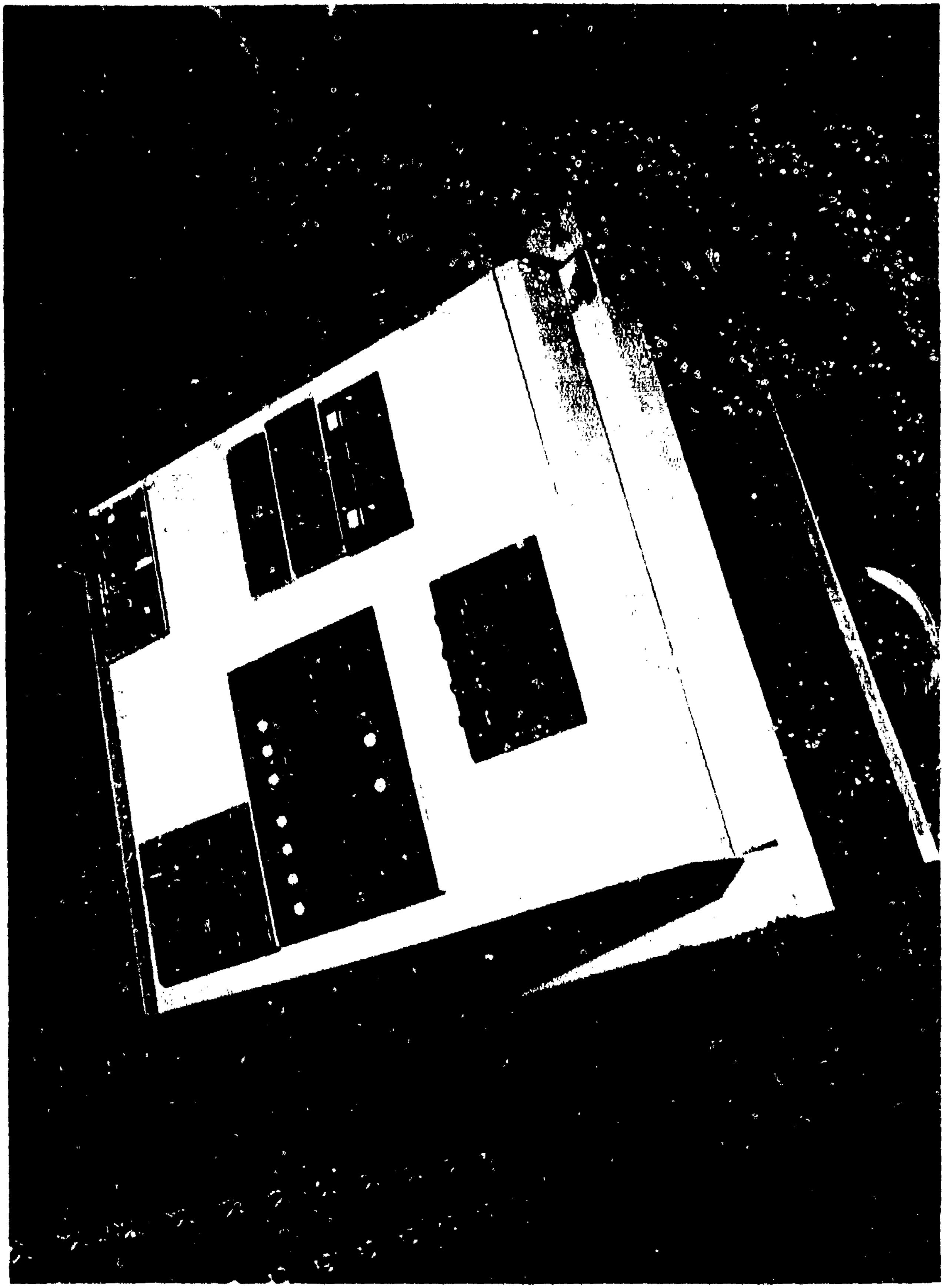


Figure 9. Cargo Compartment Forward Control Console



e. Experimenter Stations. Six experimenter stations provided the capabilities to control mission and environmental simulation; to visually monitor subject performance throughout TAWS flight profiles; to execute certain objective and subjective data collection events; to provide a realistic environment of simulated air-to-air and air-to-ground communications; and to maintain a safe operating environment.

2. Experimental Design and Procedures. Experienced C-130 crews flew a simulated AMST aerial delivery and airland mission scenario. During the flights, subjective and objective evaluations were conducted. Subjective evaluations of the flight deck and cargo compartment were conducted to address the primary program issues of flight deck and cargo compartment crew complement, avionics integration, and other crew system requirements. Two of the issues were further addressed by objective evaluations: 1) the impact of different route segments on workload and 2) the impact of different avionic configurations on workload. The subjective and objective evaluation methods are presented separately in this section. Prior to discussing the evaluation methods, aircrew subject profiles and the mission scenario flown during the evaluation are described.

Subject Aircrews. The subjects consisted of eight crews, each crew consisting of two pilots and one loadmaster with C-130 and in some cases prototype AMST experience. The crews came from the 317th TAW, Pope AFB, N.C.; the 314th TAW, Little Rock AFB, Arkansas; Hq MAC, Scott AFB, Illinois; AFTEC, Edwards AFB, California; 22nd AF, Travis AFB, California; and the Instrument Flight Center (IFC), Randolph AFB, Texas. The crews were selected to represent a wide range of experience levels and qualifications.

Pilots. The C-130 qualifications and experience levels of the pilots used for data collection are shown below. Information relating to the pilot of each crew is listed first; the copilot second.

Crew No.	From	Qualification	C-130/Total Flying Hours of Experience
1	Scott	IP	2300/2700
1	Scott	AC	1000/3700
2	Pope	IP	2400/4000
2	Pope	CP	900/1100
3	Edwards	IP	5000/5500
3	Edwards	AC	1400/1800
4	Little Rock	IP	2800/3100
4	Little Rock	CP	900/1100
5	Pope	AC	1200/1500

Crew No.	From	Qualification	C-130/Total Flying Hours of Experience
5	Pope	CP	600/ 800
6	Scott	IP	3500/7000
6	Little Rock	AC	1000/1300
7	Edwards	IP	4200/4700
7	Randolph	AC	900/3200
8	Little Rock	AC	1000/2500
8	Little Rock	CP	500/ 700

6 IPs, 6 ACs and 4 CPs: C-130 Avg: 1850 hours
C-130 Range: 500 to 5000 hours
Total Avg: 2800 hours
Total Range: 700 - 7000 hours

NOTE: IP-Instructor Pilot
AC-Aircraft Commander
CP-Copilot

Loadmasters. The C-130 qualifications and experience levels of the loadmaster are shown below:

Crew No.	From	Total Hours	Hours C-130
1	Travis	7200	2500
2	Pope	2500	2100
3	Edwards	10000	300
4	Little Rock	1500	1500
5	Pope	2500	1400
6	Scott	7000	5000
7	Pope	3500	3500
8	Little Rock	2900	2900

C-130 Avg: 2400 hours C-130 Range: 300 to 5000 hours
Total Avg: 4600 hours Total Range: 1500 to 10,000 hours

Mission Scenario (Figure 11). The mission scenario flown during subjective evaluation in the simulator consisted of the following mission profiles:

Profile 1: A nine ship flight makes a night/weather departure from Rhein Main Air Base, West Germany. The first sortie is a night,

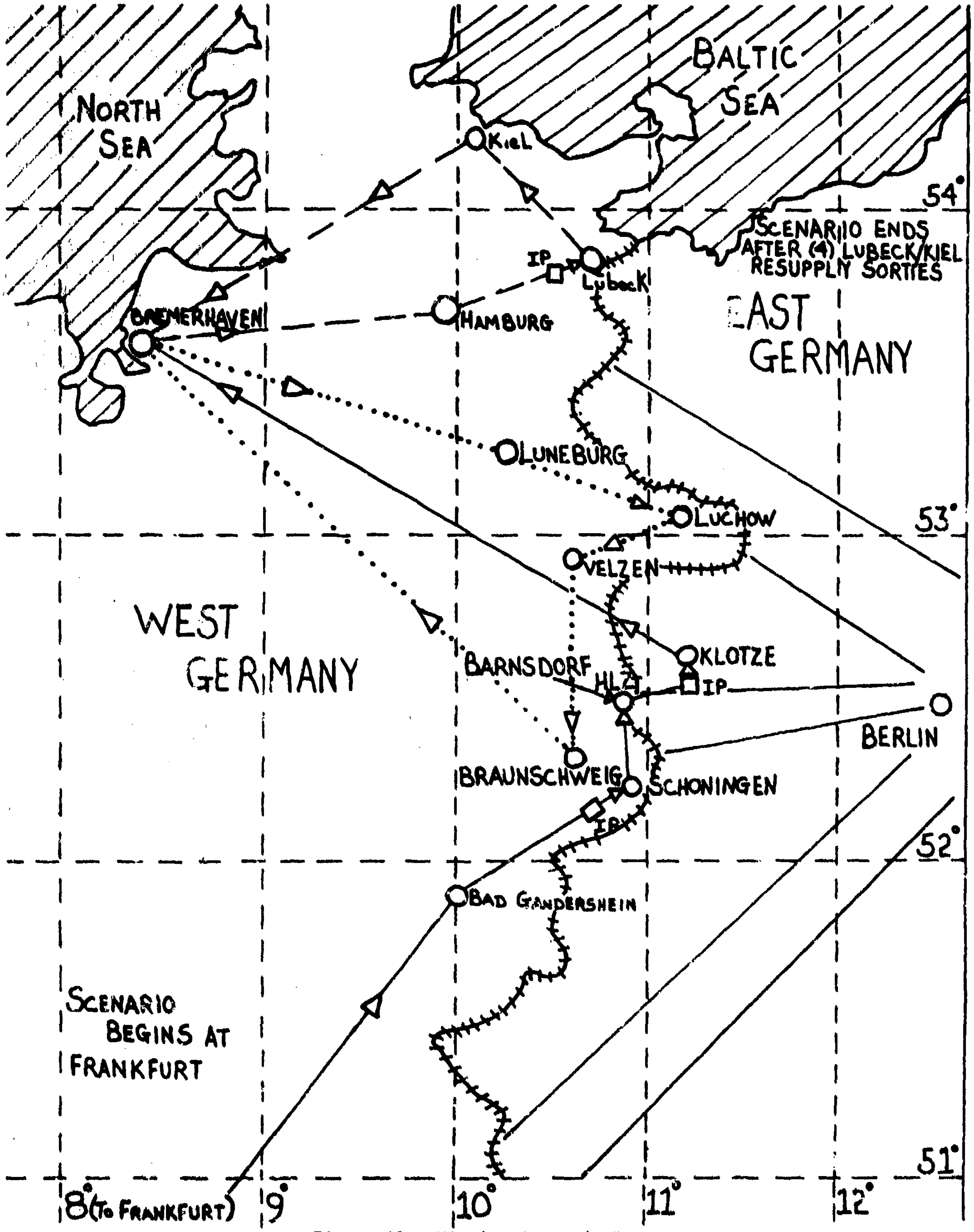


Figure 11. Mission Scenario Route

weather, SKE, medium altitude, heavy equipment, aerial delivery in support of U.S. Army tactical ground forces along the East/West German border at Schoningen drop zone (DZ).

Subject aircraft and crew (call sign BLUE 4) experiences an aerial delivery malfunction. Malfunction is resolved and a successful aerial delivery is accomplished at Schoningen. BLUE 4 breaks formation for a second sortie which is a single ship, low level, high threat, Visual Meteorological Conditions (VMC) special forces troop drop near Klotze, located inside East Germany, while the remainder of the formation recovers at Bremen and Bremerhaven, West Germany. BLUE 4 experiences and resolves a troop drop malfunction at KLOTZE and recovers with a precision approach and a STOL strip landing at Bremerhaven.

Profile 2. At dawn, BLUE 4 makes a STOL departure from Bremerhaven for a single ship, VMC LAPES delivery at Luchow, located along the East/West German border. Due to conflicting traffic, the route of flight to Luchow is changed enroute. After resolving a LAPES malfunction at Luchow DZ, BLUE 4 accepts a tactical emergency diversion to a VMC, austere landing zone located at Barnsdorf, West Germany, in a high threat environment. A combat offload is performed at Barnsdorf, after resolution of an offload malfunction. BLUE 4 then departs for Bremerhaven(with nav aids jammed)where an area navigation (RNAV) approach is flown to published weather minimums. An engine failure during the RNAV approach is resolved and a STOL strip landing is accomplished without further incident.

Profile 3. BLUE 4 is alerted for four aerial delivery sorties in response to a tactical emergency resupply requirement in a high threat area called Lubeck, which is situated along the East/West German border. BLUE 4, leader of a three ship formation, accomplishes a night, weather, STOL strip departure from Bremerhaven. Air traffic control difficulties are encountered enroute to Lubeck DZ where BLUE 4 delivers eight Container Delivery System (CDS) bundles on a night low level VMC air drop. The formation recovers from the Lubeck DZ and proceeds to Kiel, where medical supplies are delivered following a night, weather ADF approach to published minimums and a STOL strip landing. The formation makes an uneventful return to Bremerhaven. BLUE 4 flight repeats the emergency resupply mission to Lubeck and Kiel an additional three times. This terminates the TAWS scenario.

a. Subjective Evaluation. The subjective evaluation consisted of the aircrew's responses to a series of questionnaires that directly addressed the crew complement and crew systems issues. Questionnaire data were gathered before, during and after flying the mission profiles. Subjective data were also collected from each crew during a debriefing session conducted at the conclusion of all mission flying.

(1) Flight Deck Evaluation. The subject pilots flew the mission scenario profiles in a simulated mission environment. The subject pilots were instructed to perform all inflight duties including mission management, communications, navigation, aerial deliveries, normal and emergency checklists while maintaining normal aircraft control. Each mission included a departure, a resupply mission, an IMC or VMC approach and a landing.

After the previously described mockup evaluations, there remained some doubt as to the optimum level of avionic sophistication in terms of both costs and workload. Therefore, four levels of avionics sophistication were investigated at predetermined times during the missions, for both subjective and objective data collection purposes as follows: Level 1) all simulated avionics were available; Level 2) no autopilot; Level 3) no bulk data storage (BDS) for the navigation system; and Level 4) no autopilot and no BDS. The bulk data storage capability was a conceptual solution involving an extensive NAV management computer memory that was used to store an entire theater of navigation aids and waypoints. The BDS also provided the capability to program an extensive flight plan or a series of flight plans in the NAV management computer memory. Without the BDS capability, the conceptually limited computer memory provided no navigation aids or waypoints stored in memory and the flight plan was limited to ten waypoints plus an aerial delivery computation capability. Other avionics configurations tested included specially designed instrument panel alphanumeric readout information, and keyboard frequency tuning capabilities.

Various crew systems issues were addressed in three pilot questionnaires. Questionnaire #1 included questions about the alphanumeric readout information, the SKE, autopilot, flight director and VAM concepts and the utility/placement of various displays. Questionnaire #2 addressed the capabilities and design concepts of the navigation system, integrated communication/navigation system and aerial delivery system. A final questionnaire included questions concerning the division of workload and questions addressing crew complement. Each pilot completed all three questionnaires following the final mission profile flight. The pilots were also debriefed and their comments were recorded.

(2) Cargo Compartment Evaluation. During the first two mission profile flights, a loadmaster was located in the cargo compartment mockup. He was asked to perform or simulate the performance of his normal duties including normal equipment checks, drop checklists and communicating with the flight deck. Simulated emergencies and malfunctions presented to the loadmaster during the airdrops included a heavy equipment hung load, a LAPES toe-plate malfunction, a hung paratrooper, and a jammed load during a combat offload.

The cargo compartment issues were addressed in a loadmaster's questionnaire which included sections on airdrop malfunctions, crew complement and equipment requirements. A debriefing session was conducted and the loadmaster's comments were recorded. The issues concerning the interaction of the flight deck and the cargo compartment were addressed in both the pilot's and loadmaster's questionnaires as well as both debriefing sessions.

(3) Procedures. First Day. Prior to the subjective evaluation flights, each subject pilot crew received training on the use of the crew systems and the simulator. The training was designed to provide the aircrews enough avionics and simulator familiarization to address the crew complement and avionics issues while flying a series of simulated tactical transport missions. The first day included TAWS avionics classroom training and simulator flight traffic pattern takeoff and landing training. The classroom training concentrated on program familiarization and crew systems training. The traffic pattern training involved the use of both CTOL and STOL configurations for takeoff, traffic patterns and landings, providing each pilot with two and a half hours of pilot and two and a half hours of copilot flying training time.

Second Day. The second day was also devoted to training which included additional avionics classroom training and simulator flight training. The classroom training period concentrated on the operation of the integrated communication/navigation system, while the flight training consisted of a cross-country round robin, allowing the subjects to exercise most of the various capabilities of the integrated communication/navigation system. Each subject pilot flew the same round robin two times, once from the pilot seat and once from the copilot seat. Various levels of avionics capabilities were presented to the pilots during the two round robin training flights. The levels of avionics capabilities presented were the same as those previously described under "Flight Deck Evaluation" (pg. 24).

Third Day. On the third day, in final subject preparation for flying the full tactical mission profiles, the loadmaster received classroom training and orientation concerning the operation of the loadmaster stations, the aerial delivery systems and the interacation of the cargo compartment mockup with the TAWS full mission simulation (Figure 12, 13). Meanwhile, the subject pilots were completing their classroom training on the TAWS avionics systems, including the operation of the aerial delivery system.

Following the classroom training session, the first two mission scenario profiles were flown for the dual purposes of providing a broad basis for subjective evaluations and to better prepare the subject crews for flying the final mission scenario profile, during which time, objective as well as subjective data were generated. Prior to flying each mission profile, the subject pilots and loadmasters were given a complete tactical mission pre-flight briefing covering the various aspects of weather, threat, load, drop zones and landing zone. All routine, mission related paperwork and maps supporting the mission were reviewed by the subject crew prior to departure. (To save time, all mission paperwork was previously prepared for the crews.)

During the first two mission profiles, avionics status was varied so that the pilots could evaluate the benefits of the autopilot capabilities, the bulk data storage capabilities, the instrument

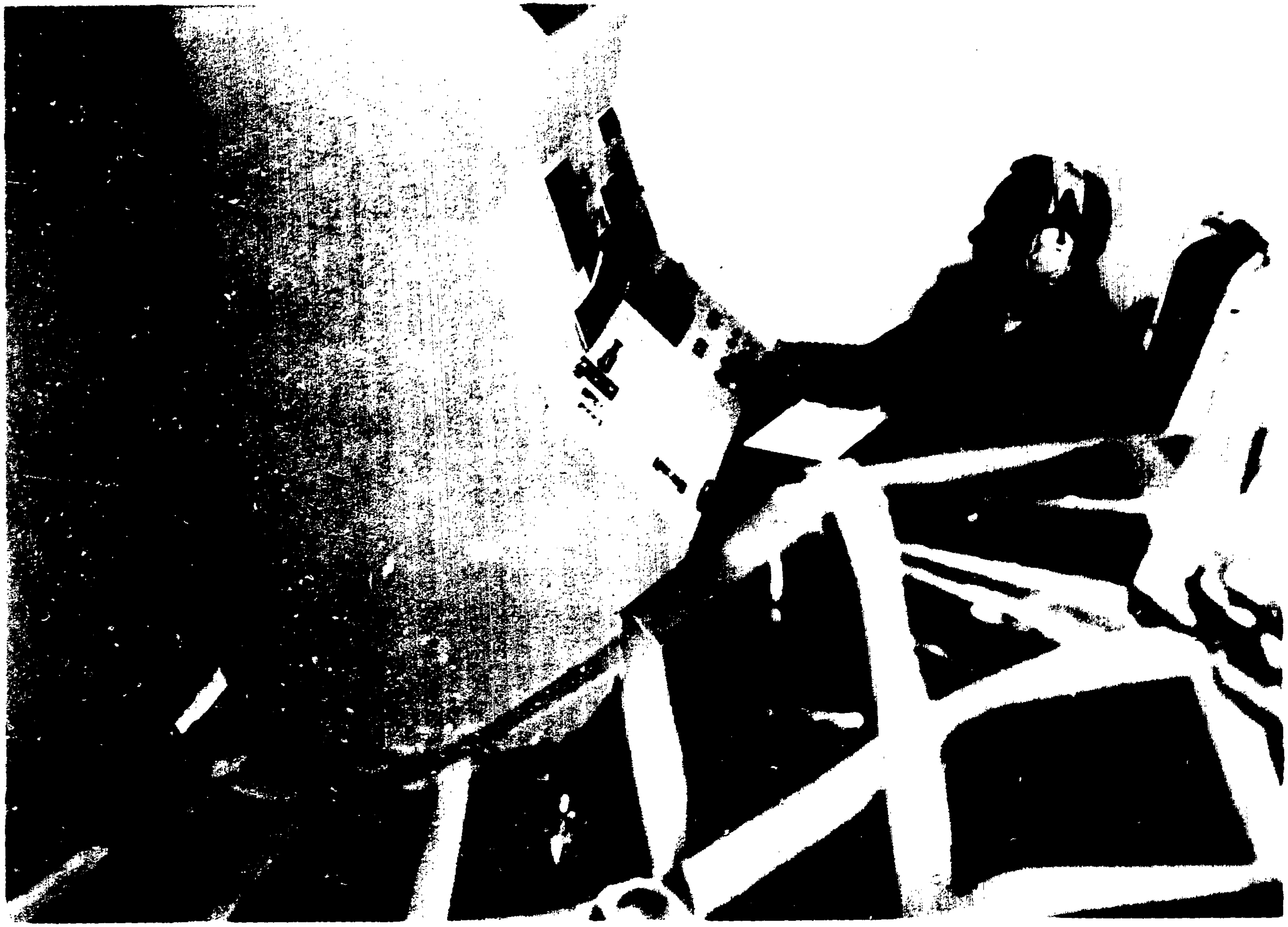


Figure 12. Loadmaster at Forward Cargo Compartment Control Console

Figure 13. Loadmaster at Aft Cargo Compartment Control Console

panel alphanumeric readout information (for RMI, HSI, and aircraft performance) and the benefits of using the keyboard for tuning the communication system.

The pilots switched seats after each mission profile. Cargo release malfunctions and one engine failure were encountered, allowing the subjects to simulate the resolution of the malfunctions. During the mission flying, the loadmaster maintained normal communications with the flight deck, accomplished all routine checklists and attempted to resolve the simulated cargo compartment malfunctions in coordination with the pilot's direction.

Fourth Day. The final mission profile was briefed and the mission materials were reviewed by the subject aircrews. (The loadmaster did not participate during the final mission profile. However, his duties were performed by an experimenter.) The crews repeated the final mission profile four times, with a different avionics status on each mission. There were air traffic control and threat distractions during each of the final four missions. The pilots did not switch seats between the final mission sorties. Questionnaires were completed by the pilots after each of the final sorties. The questionnaire asked the pilots to rate the difficulty and workload associated with the mission flights. These ratings, were combined with objective data to evaluate the crew's performance.

b. Objective Evaluation. The objective evaluations were conducted in conjunction with the (previously described) final subjective evaluation flight profiles. For the purpose of objective data collection, the aerial delivery mission was subdivided into three route segments. These three segments were: 1) an enroute cruise segment which began as the aircraft leveled off after takeoff, 2) a segment immediately before the initial point (IP) for the aerial delivery, and 3) a segment from the IP to the end of the drop zone.

(1) Flight Deck Experiment. Required avionics capabilities were investigated by collecting objective data during the final four tactical resupply mission sorties. The previously described four levels of avionics sophistication were presented to the crews while several objective parameters were recorded to measure the crew's performance.

(a) Objective Parameters. Course deviation, altitude and airspeed were measured during the four data sorties. The course deviation (the distance between the aircraft's position and the desired HSI course), altitude and airspeed were recorded on magnetic tape every seven seconds. The tape recording was marked with an "event marker" when the aircraft reached the first turnpoint, the IP, and the CARP in order to separate the data for the three route segments.

The crew's performance was also measured by recording the CARP accuracy for each drop. The CARP accuracy scores included course deviation, altitude deviation, and airspeed deviation. The accuracy scores were computed by comparing the aircraft's position at

the drop with the desired CARP position.

A secondary task of time estimation was used to measure pilot and copilot workload. Previous research (Ref. 8) indicates that the length of a subject's time estimate will vary with the difficulty of concurrent primary tasks. It was assumed that increases or decreases in the difficulty of the flying, communication, and navigation tasks would cause parallel increases or decreases in the length of the subject's time estimates. Therefore, the pilots and copilots were asked to estimate several 10 second intervals during the data flights. The subjects estimated the 10 second interval by starting and stopping a digital timer whenever they heard a designated tone in the headset, which was initiated by the experimenter. The pilot controlled a timer via a response key on the yoke. The copilot's response key was located on the side console. The subjects were asked to produce 7 estimates during each flight (1 during takeoff, 2 during cruise, 2 during the IP segment, and 2 during the CARP segment).

(2) Procedures. Since the final flight profile was flown for the dual purpose of collecting both subjective and objective evaluation data, the pilot procedures that are described under subjective evaluation for the final profile need not be repeated in this section. However, it should be noted that the order of presenting the four different levels of avionics capability (as described earlier in "Flight Deck Evaluation", page 24) was counterbalanced by a Latin Square.

During the data collection flights, the experimenters recorded the objective data. The cab experimenter recorded the time estimates and coordinated the run numbers with the computer deck. The computer deck experimenters recorded performance deviations.

E. Method Summary

The avionics issues relating to the use of a two-pilot/one loadmaster crew for the AMST mission were addressed through full mission simulation. The evaluation included a simulated tactical mission with multiple sorties, and the collection of questionnaire data from the pilot and loadmaster subjects before, during and after the mission profile flying. The final flight profile, included an experiment concerning pilot performance with different levels of avionics sophistication and integration, and a parallel experiment concerning workload as affected by avionics levels. The data gathered from the evaluations were reduced and analyzed. The results of this process are described in the following section.

SECTION III

RESULTS

The results from both the subjective and objective evaluations are described in this section. The questionnaire and debriefing comments were summarized and presented in the form of charted graphs of subjects' responses. The objective results are presented on graphs of subject flight performance data and workload (time estimate) data.

Subjective data are presented as follows:

1) Crew complement data
2) Navigation and communication data
3) Autopilot, HUD and other crew systems data
4) Cargo compartment data

Objective data follows:

1) Performance Data: Typical Flight Profile
2) Performance Data: With and Without Autopilot
3) Performance Data: With and Without Bulk Data Storage*
4) Workload Data: Time Estimates
5) Workload Data: Subjective Workload Ratings

*NOTE: Bulk Data Storage or BDS is the terminology used to identify an extensive nav management computer memory capability which was one of two candidate conceptual solutions to the issue of required nav management capacity.

No Bulk Data Storage or NO BDS is the term used to indicate a limited nav management computer memory.

A. Subjective Data

The following subjective data are the result of questionnaire responses collected from each of the 16 subject pilots and each of the 8 loadmasters. Pilot questionnaire data were collected after each of the four final sorties. Subsequent to all TAWS mission flying, each pilot completed two overall questionnaires: a pilot questionnaire and a copilot questionnaire. The loadmasters also completed an overall questionnaire at the completion of their TAWS flying activities. The pilot and loadmaster debriefing comments are also represented in the following subjective data results. Subjective rating scales varied from dichotomous yes/no responses to a four level rating of required capabilities.

Subjective workload ratings are presented in the objective data subsection along with the objective workload data for better continuity.

CREW COMPLEMENT RESULTS

All pilot subjects responded that the AMST mission could be flown by a flight deck crew of only two pilots, if adequate avionic capabilities (as identified by the pilot data) were provided.

Both the pilots' and loadmasters' data established the criteria for an additional crew member (ACM) in the cargo compartment for safety considerations on tactical missions. A crew chief type ACM was rated as a necessity to aid in aircraft turnaround at austere locations. The pilots also rated an ACM as a desirable addition to the flight deck to assist in "see and avoid", system monitoring and checklist utility.

The "Pilot Complement" ratings on the following page are defined as:

YES

NO

The additional crew member (ACM) or crew chief ratings on the following page are defined as:

REQUIRED

EXTREMELY USEFUL

MODERATELY USEFUL

NOT USEFUL

NOTE: Each of the following crew complement bargraphs represent 16 pilot responses. "NA" indicates no answer.

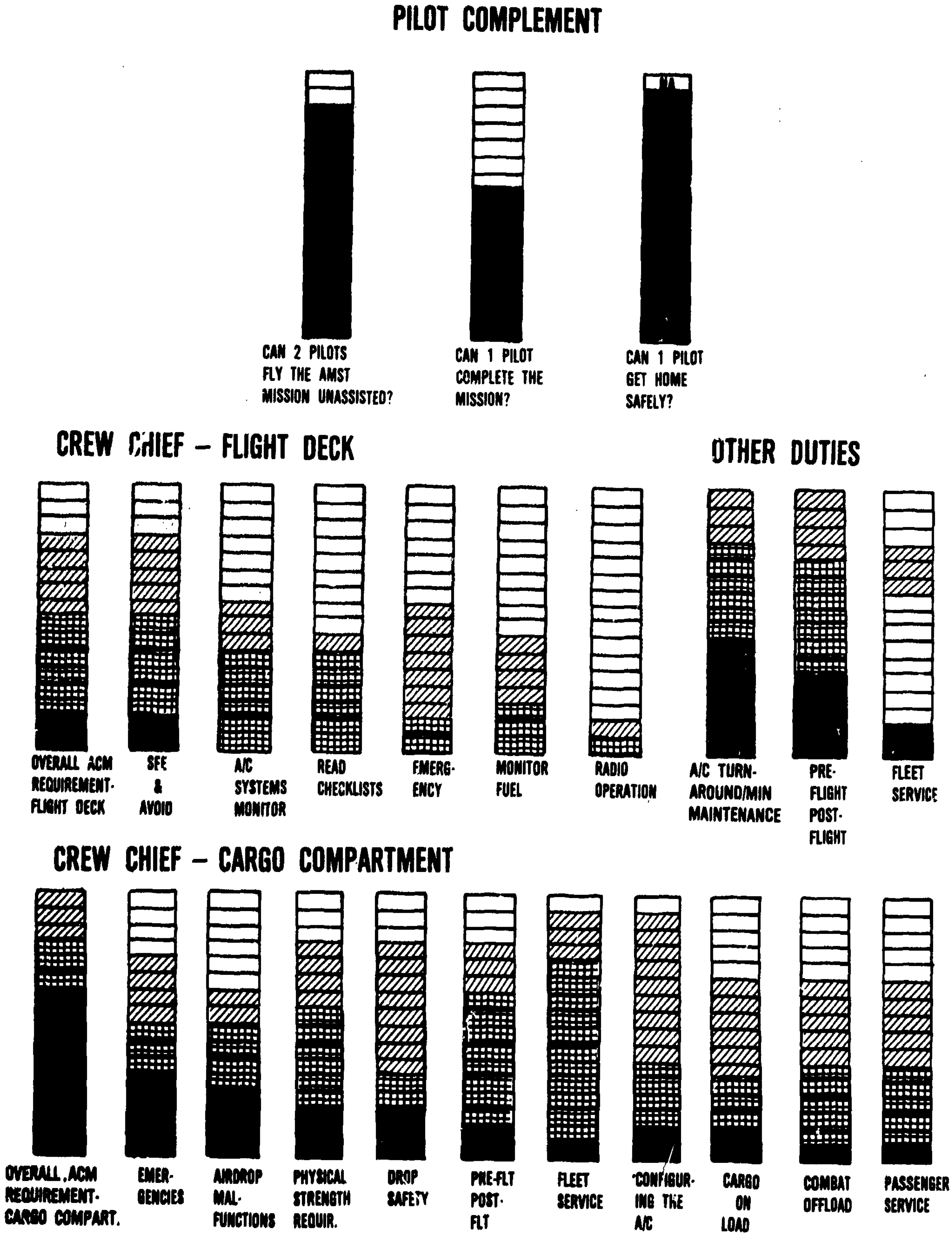


Figure 14. Crew Complement Data

NAVIGATION SYSTEM RESULTS

Pilot responses indicate the following: Integration of the INS/multi-sensor navigation system is a design requirement for a two-man flight deck crew. The integrated navigation system must provide for flight plan entry and automatic flight plan update capability with waypoint data readout information and an integrated aerial delivery capability. Important features include bulk data storage, dual control/display units, automatic navigation and tuning, progress/position information and symbolic map information.

COMMUNICATION SYSTEM RESULTS

The pilots' response to communications were: Integration of the communication system is a design requirement. A dual tuning capability such as an alphanumeric keyboard and a set of manual tuning knobs is required. Active frequency information must be displayed. Important features include: transmitter selector information (lights); standby frequency display with active/standby transfer capability and a tuning keyboard for each pilot.

ALPHANUMERIC READOUT RESULTS

The pilots indicate that required alphanumeric information on the instrument panel is: a time to CARP readout; HSI navigation aid/waypoint identifier, time and distance readouts; and a groundspeed readout. Important instrument panel information is: RMI navigation aid/waypoint identifier and distance readout; true airspeed and drift.

NOTE: The bargraphs on the following page are defined as follows:

REQUIRED

EXTREMELY USEFUL

MODERATELY USEFUL

NOT USEFUL

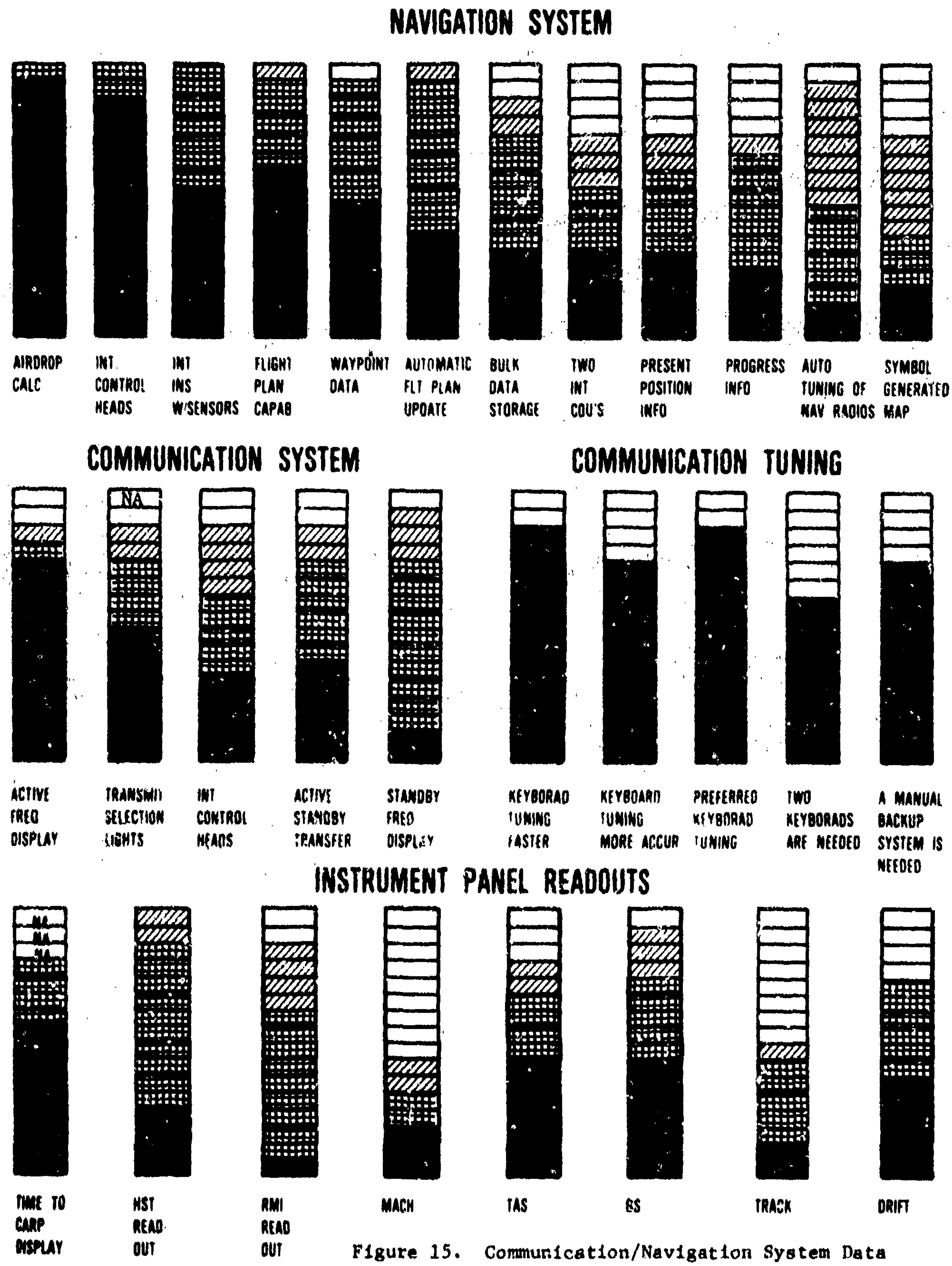


Figure 15. Communication/Navigation System Data

AUTOPILOT RESULTS

Some autopilot capability requirement exists for the AMST. Half the subject pilots identified it as a required capability while the other half rated the autopilot somewhere between extremely and moderately useful. Pilots identified necessary autopilot capabilities as: heading control; altitude control; navigation and aerial delivery coupling. Important autopilot characteristics were approach, vertical velocity and SKE coupling.

VISUAL HEAD UP DISPLAY RESULTS

Pilots indicated that a visual augmentation device with aimpoint information displayed for visual touchdown point acquisition and landing is a required capability. Important features include AOA information and a separate visual presentation for both pilots. The pilots are split over AOA and airspeed information preference with some indication that both should be presented on the visual head up display.

OTHER CREW SYSTEMS RESULTS

The pilots' responses showed that flight director information is required while an automatic SKE timing capability is an important feature. The subjects prefer a center stick over the yoke or other controllers.

Autopilot bargraphs are defined as:

YES

NO

Instrument/visual guidance and SKE bargraphs are defined as:

EXTREMELY USEFUL

MODERATELY USEFUL

SLIGHTLY USEFUL

NOT USEFUL

The bargraphs for aircraft controllers are defined as:

FIRST CHOICE

SECOND CHOICE

THIRD CHOICE

FOURTH CHOICE

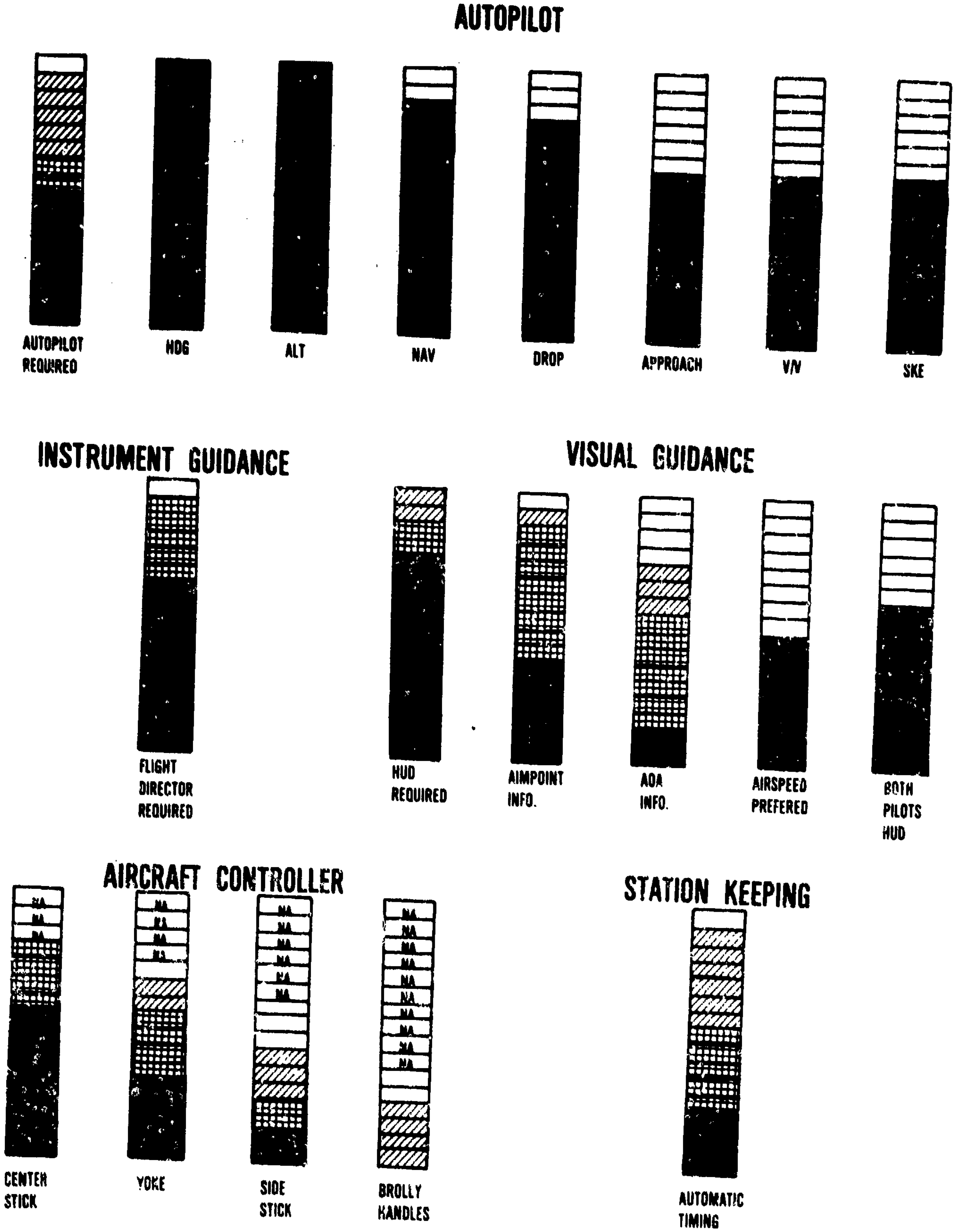


Figure 16. Aircrew Systems Data

CARGO COMPARTMENT RESULTS

The loadmasters identified the requirement for an additional crew member, primarily for safety considerations during aerial delivery missions.

All loadmasters agreed that control consoles must be located forward and aft. Required capabilities for the forward and aft consoles include: ramp and door control; AIC 18 type comm system; winch control; lighting control. The forward console capability must also include: public address; O_2 control; cabin temperature control and APU control. Equipment concepts desirable were: overhead comm cable and elevated forward console.

The following bargraphs are defined as follows:

EXTREMELY USEFUL

MODERATELY USEFUL

SLIGHTLY USEFUL

NOT USEFUL

NOTE: The bargraphs on the following page represent eight loadmaster responses.

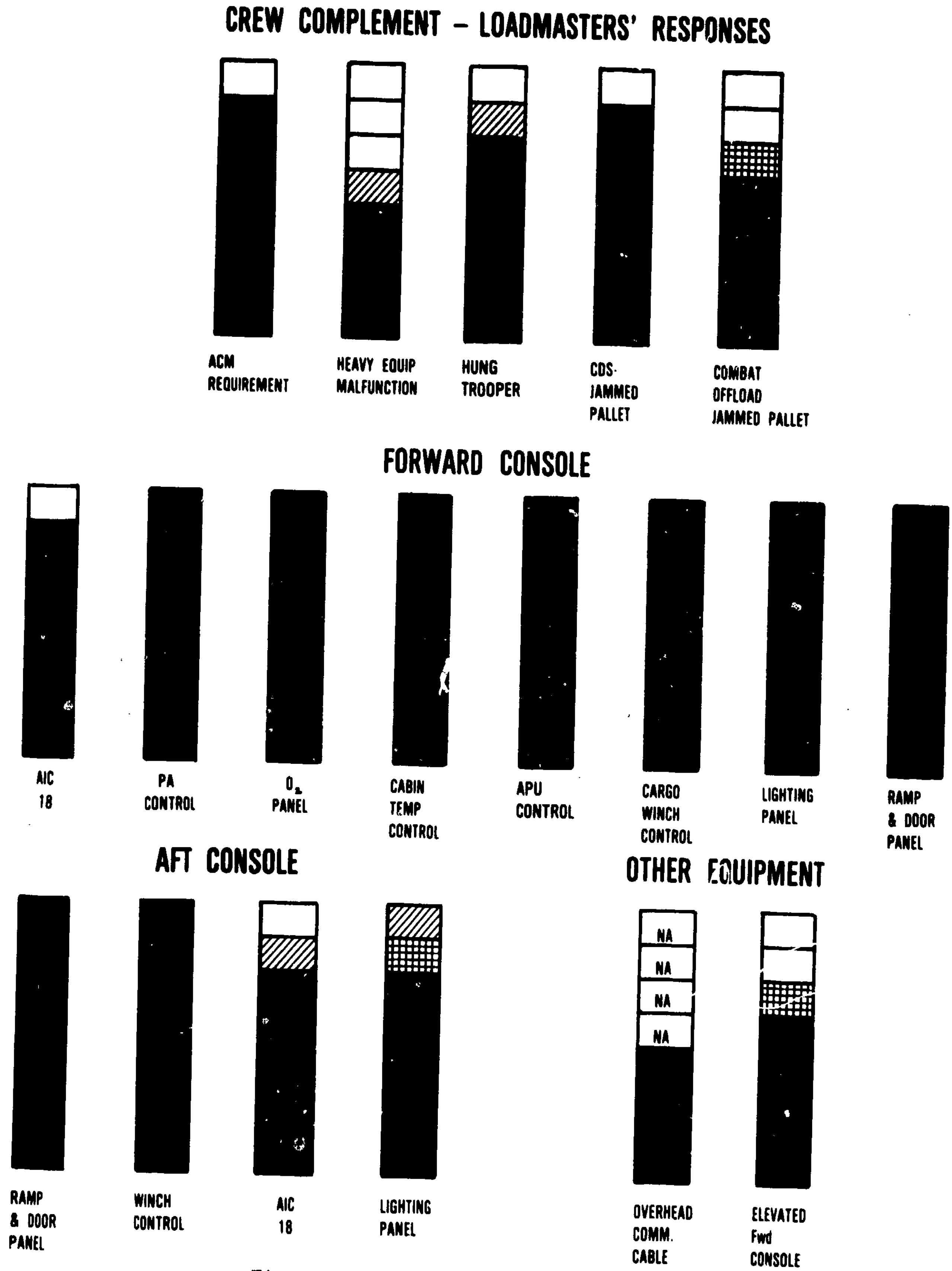


Figure 17. Cargo Compartment Data

B. Objective Data

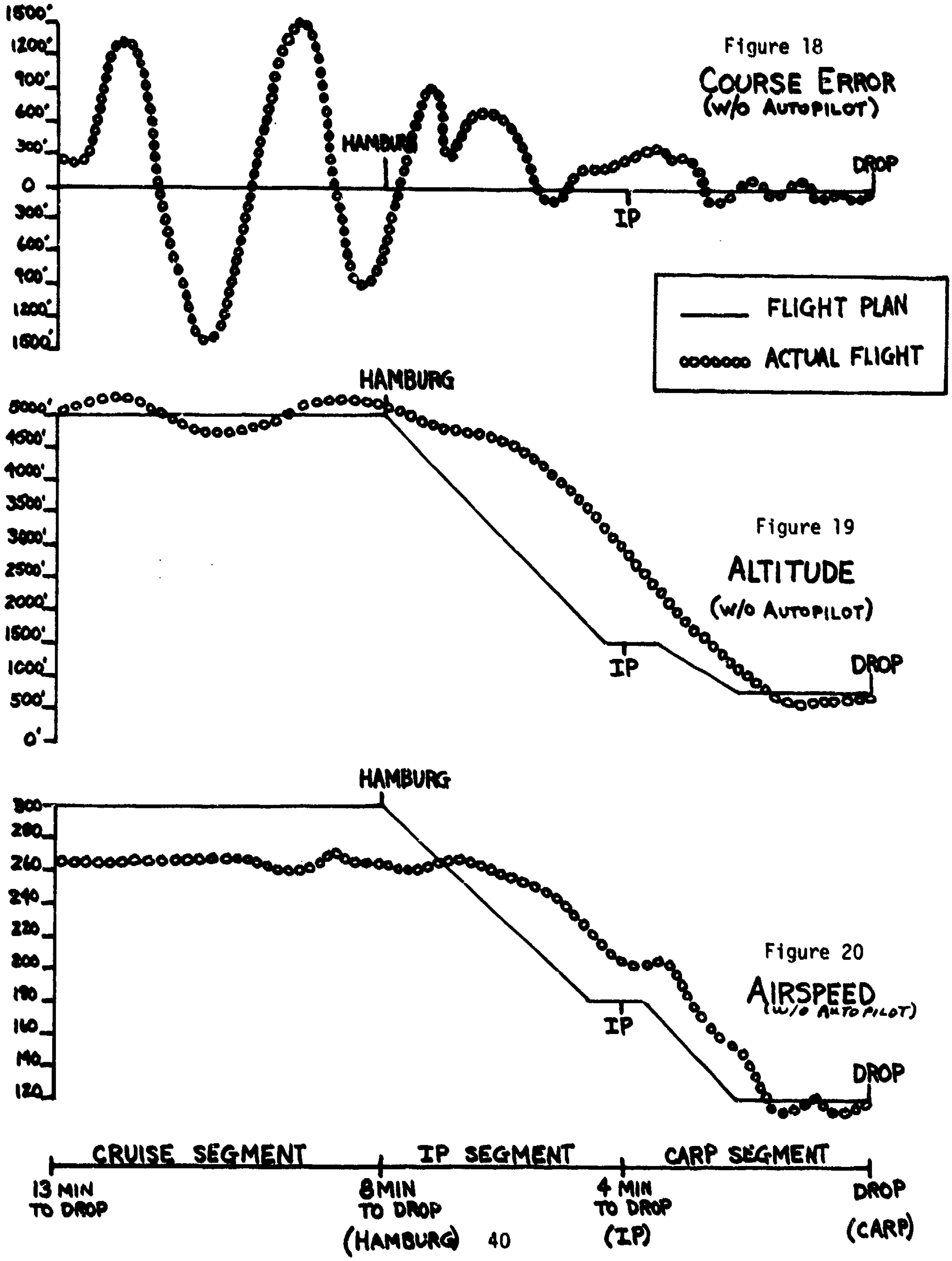
The objective data were recorded during thirty-two data flights (four flights/crew). The data mission, experimental conditions, and procedures are described in the Methodology Section (pp. 4-20). The objective data consist of two types of parameters: 1) the performance data which include the course, altitude, and airspeed data; 2) the workload data which include the time estimates and the subjects' workload ratings.

PERFORMANCE DATA: TYPICAL FLIGHT PROFILE

The course error, altitude, and airspeed profiles for a typical flight are illustrated in Figures 18, 19 and 20. These particular profiles were selected to represent the general characteristics of all of the data flights, although the profiles are not actually averages of all flights. In these diagrams the X-axis (horizontal axis) is a time reference as is described at the bottom of the page. It should be noted that the distance scales are not proportional for the X and Y axes, and as a result the course error variations appear to be more extreme than they actually were.

Figure 18 is a typical course error profile when the autopilot was non-operational. The course deviations appear large during the cruise segment and gradually decrease until they become minimal at the drop point. The course error profile (not shown) for a typical flight with the autopilot operational would be depicted by a straight line, virtually on course, with almost no variation. The altitude graph (Figure 19) shows a typical vertical profile for a flight without an autopilot. There are small fluctuations in altitude during the cruise segment, the altitude flown is generally higher than desired during the descent (IP segment), and then the altitude performance becomes very accurate at the drop. The altitude profile with autopilot (not shown) is similar to the "without" autopilot profile. This apparent inconsistency with expected autopilot altitude accuracies was due to a persistent unprogrammed mechanization problem during data flights. The airspeed graph (Figure 20) shows the general trend for the aircraft to be slow during the cruise, fast during the slowdown ([illegible] segment) and fairly accurate at the drop. Except at the CARP, airspeed error is consistently large . The airspeed profile did not change as a function of "with" or "without" autopilot.

PERFORMANCE DATA - TYPICAL FLIGHT PROFILE



PERFORMANCE DATA: WITH AND WITHOUT AUTOPILOT

The course error data (Figures 21 and 22) show a large, statistically significant [$p < .01$, $F(1,6) = 13.61$] difference between the autopilot and no autopilot conditions. Figure 21 illustrates the average course error at selected points during the flight (HAM, IP 1 MIN, CARP). Figure 22 shows the average error for entire segments (CRUISE, IP, CARP). In both cases there is a statistically significant [$p < .05$, $F(2,12) = 6.59$] decrease in course error from the beginning of the flight to the CARP. During the "CARP SEGMENT" (Figure 22) and at the "1 MIN TO CARP" and "CARP" points (Figure 21), the difference in course error between the AP and no AP conditions is not statistically significant. In summary, the course error is much larger for the no-autopilot condition than the with-autopilot condition. However, this difference decreases during the flight until the course error is equivalent for the two conditions at the CARP or drop point.

Figures 23 and 24 illustrate the altitude and airspeed errors for selected points during the flight. Both graphs depict a fairly consistent trend for the error scores to be greater during the no-autopilot condition. However, the differences are not statistically significant.

PERFORMANCE DATA - WITH AND WITHOUT AUTOPILOT

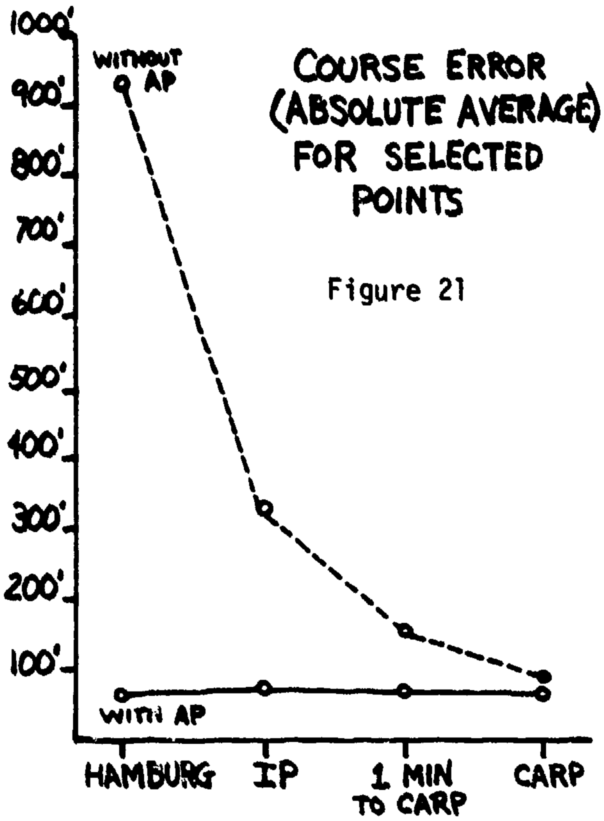


Figure 21

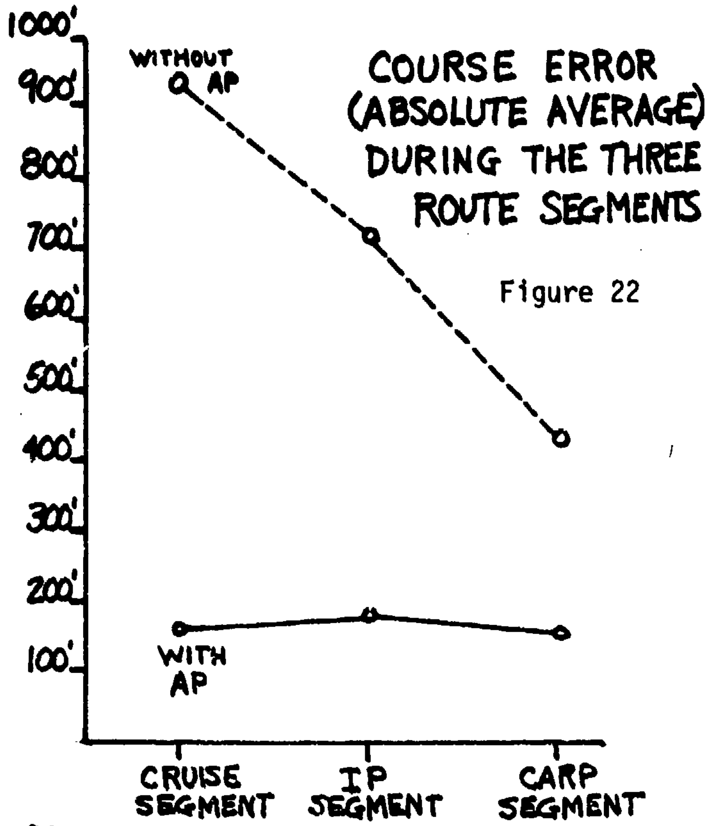


Figure 22

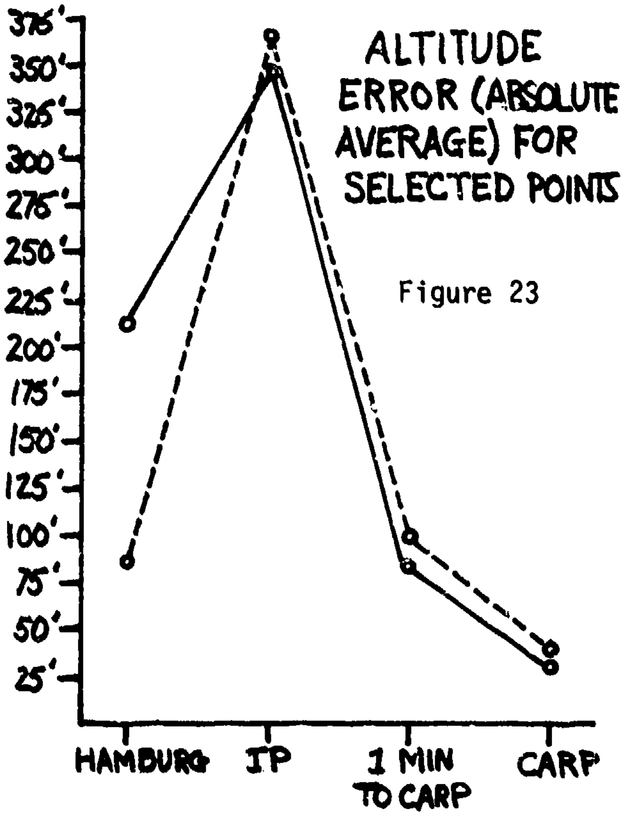


Figure 23

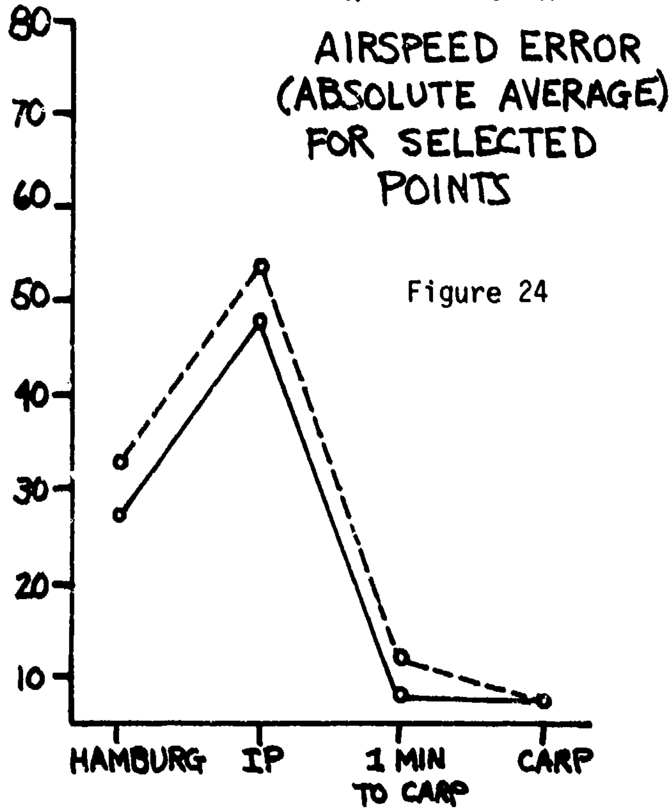


Figure 24

PERFORMANCE DATA: WITH AND WITHOUT BULK DATA STORAGE CAPABILITY

The data illustrating the effects of bulk data storage (BDS) were reduced for two different portions of the flight: for the cruise segment (Figures 25 and 26), and for selected points after Hamburg (Figures 27, 28, and 29). This was done to isolate the effects of a navigation task which was given to the subjects during the early part of the cruise segment. At approximately 5 minutes to Hamburg the crews received a radio call requesting that they report their position relative to a jammed navigation aid in the area. The difficulty of the task was influenced by the presence or absence of BDS. If BDS was present, the crew could find their relative position by keypunching the three letter identifier for the navigation aid into the navigation management system, and their relative position would be automatically computed. If, however, BDS was absent, the subjects needed to 1) look up the navigation aid for the location data for that station, 2) enter the new information into their flight plan, 3) manipulate the navigation management system to discover their relative position.

The performance data for the cruise segment (Figures 25 and 26) illustrate a noticeable but statistically insignificant effect for the BDS and NO-BDS conditions. The course error graph (Figure 25) indicates a larger error score when BDS was absent at 5 and 4 minutes to Hamburg. Similarly, the airspeed graph (Figure 26) shows that the crews were an average of 8 knots slower during the NO-BDS condition at 5 and 4 minutes to Hamburg. With and without BDS, average cruise airspeed error from the flight planned 300 KTS is higher than expected (10-20 KTS up to 3 minutes from Hamburg).

From one minute to Hamburg through the selected points after Hamburg (Figures 27, 28, and 29), the data show a slightly smaller error for the NO-BDS condition.

PERFORMANCE DATA - WITH AND WITHOUT BULKDATA STORAGE

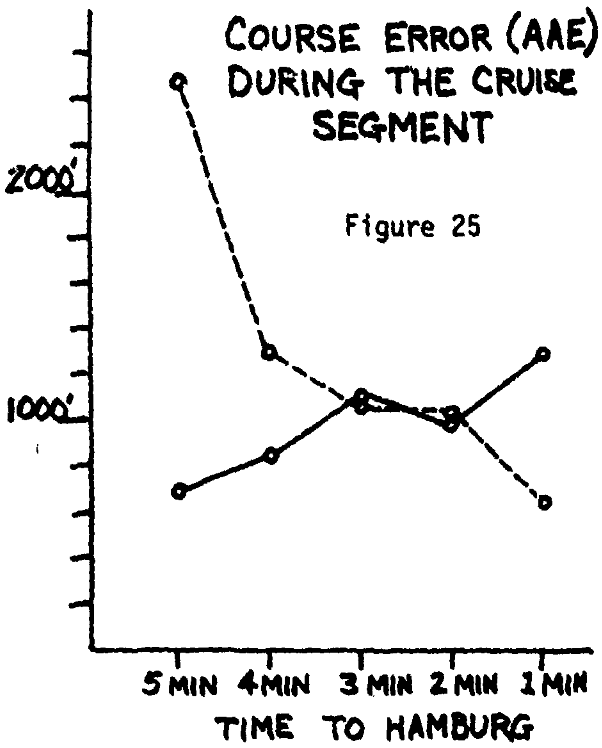


Figure 25

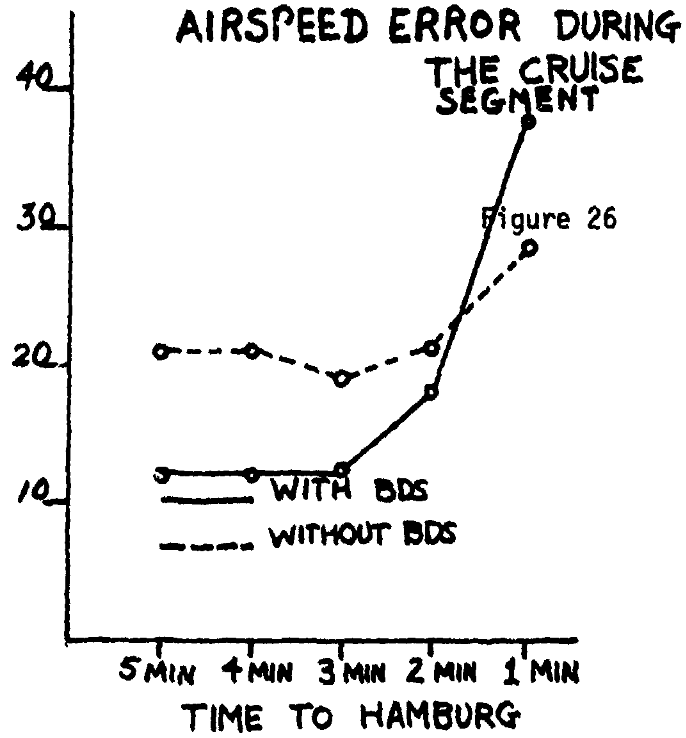


Figure 26

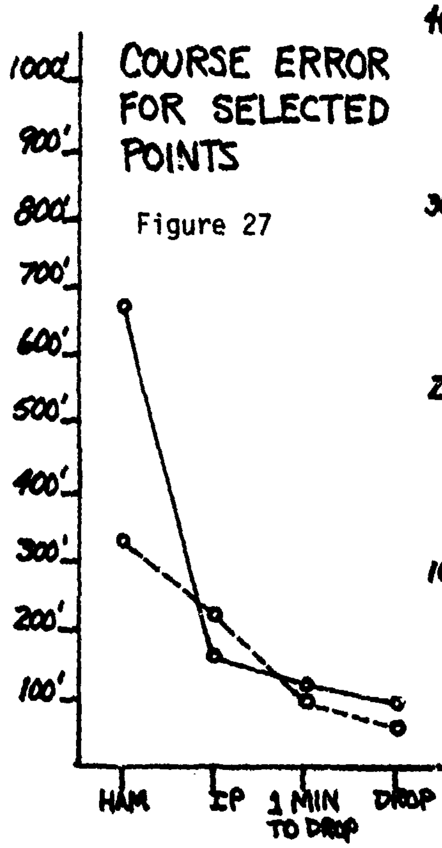


Figure 27

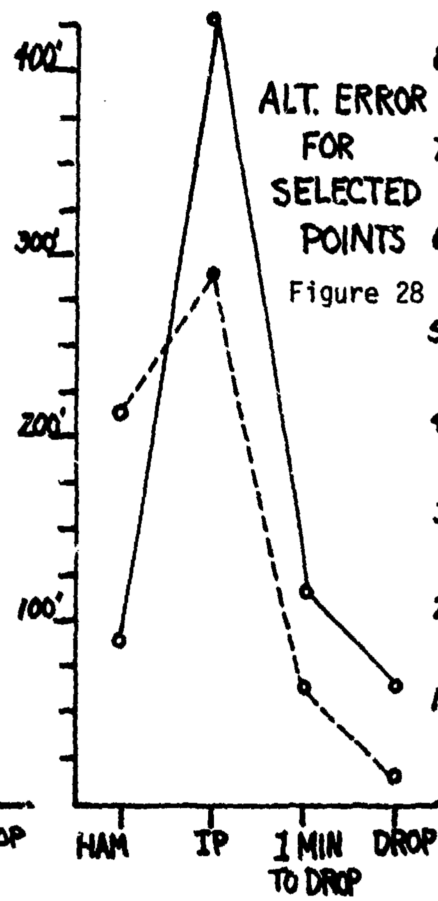


Figure 28

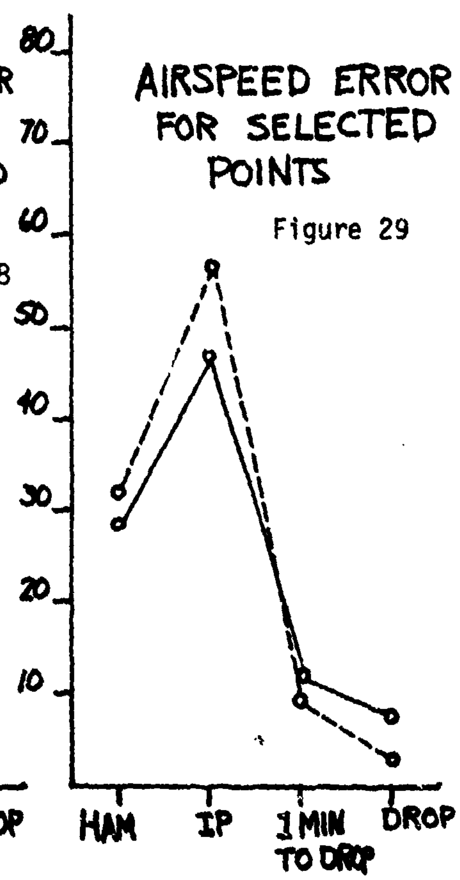


Figure 29

WORKLOAD DATA: TIME ESTIMATES

The time estimation data describes the workload profile for different parts of the data mission. The subjects failed to complete several of the estimates they were asked to make, and the incomplete estimates are used as an index of concurrent workload. Figures 30 and 32 show the percentage of estimates which were not completed during the different mission phases. Figure 30 illustrates the percentage of incomplete estimates for the seven points during the flight when the 10 sec. estimates were made. Figure 32 depicts the percentages for the three route segments. The percentage for each segment is an average of the two data points contained in each segment (CRUISE SEGMENT - 12 and 9 min. points/IP SEGMENT - 7 and 5 min. points/CARP SEGMENT - 3 and 1 min. points).

Figure 31 contains the median time estimation ratios for the seven data points. The time estimation ratio was computed by dividing each estimate by the subject's baseline estimate. A ratio of one indicates that the subject's workload estimate equalled his baseline estimate; the higher the ratio the greater the workload. The median or middle point was computed from a list of all estimates including the incomplete estimates. The incomplete estimates were assumed to be longer than the completed estimates. This assumption is based on subjective post flight data where the subject pilots stated that the incomplete estimates were the result of high task loading which in turn caused them to forget to terminate the time estimation task. Therefore, the number of incomplete estimates had a great influence on the median ratio statistics as is evident from the parallel trends in Figures 30 and 31.

Figure 33 shows the mean time estimation ratio computed from the completed estimates. The same general trend is apparent. The time estimation ratios increase from the beginning to the end of the flight. There is a statistically significant difference [$p < .05$, $F(2, 28) = 4.52$] between the time estimation ratios for the cruise segment and the IP segment; between the cruise segment and the CARP segment.

In summary, the various time estimation statistics follow the same general trend. The workload apparently increases from the beginning to the end of the flight, with the exception of the takeoff point which is slightly more difficult than the 12 minute point, and with the exception of the 1 minute point which is less difficult than the 3 minute point.

WORKLOAD DATA - TIME ESTIMATES

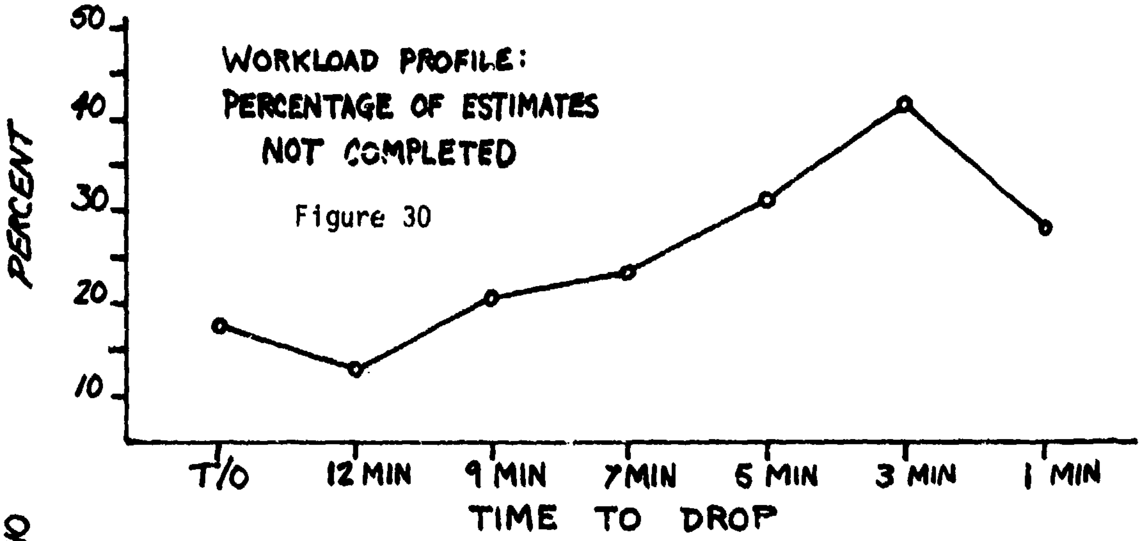


Figure 30

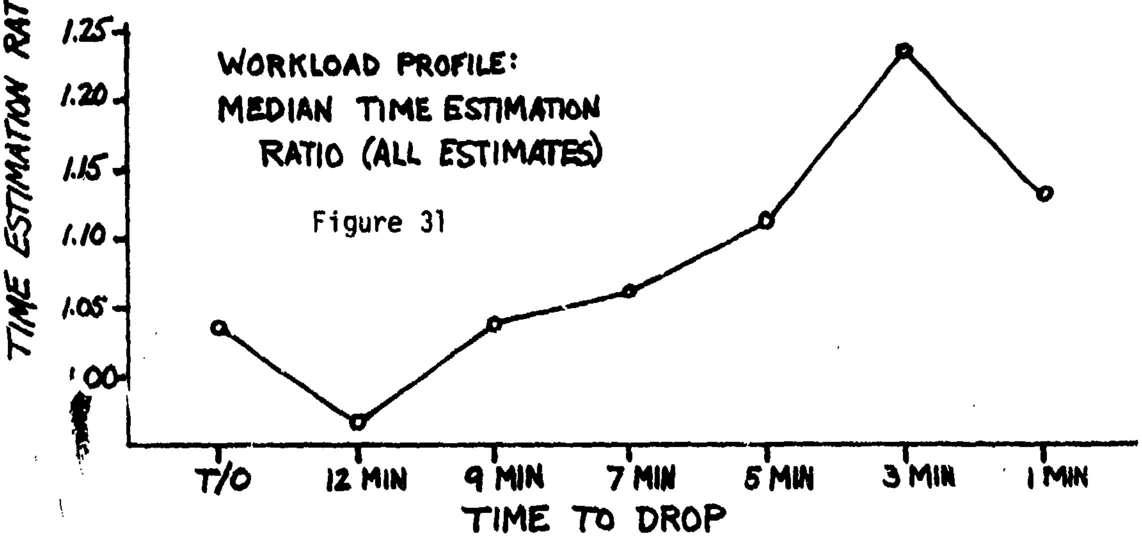


Figure 31

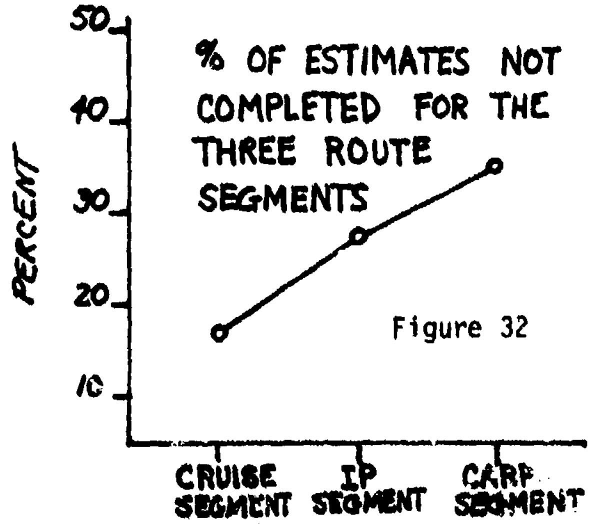


Figure 32

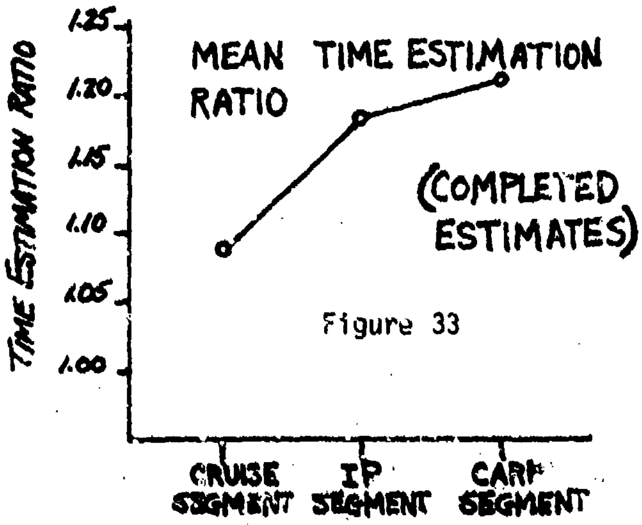


Figure 33

WORKLOAD DATA: SUBJECTIVE WORKLOAD RATINGS

The subjects were asked to rate their workload from one to ten for each route segment. A rating of one indicated that there was no work to be done; a rating of ten indicated that they were working at full capacity. Figures 34 thru 39 show the averages of those workload ratings.

All of the figures illustrate a statistically significant trend [$p < .01$, $F(2, 28) = 13.68$] of increasing workload from the beginning to the end of the flight. Figure 35 shows a consistently greater workload for the copilots. Figures 36 and 38 show the effect of the AP conditions on the pilots' and copilots' workload. The pilots (Figure 36) experienced a significantly greater workload [$p < .05$, $F(1, 6) = 6.81$] during the no autopilot condition, especially during the CARP segment where the pilots had to work harder to reduce the course and altitude error while lining up with the drop zone. The copilot's workload was not affected by the autopilot conditions (Figure 38).

The copilots, however, experienced a greater workload without bulk data storage (Figure 39). The increased workload was most prominent during the cruise segment and much less so during the IP and CARP segments. The pilots, on the other hand, showed little effect from the BDS conditions (Figure 37). The apparent difference in workload at the CARP for pilots with BDS (Figure 37) is somewhat misleading due to the ordering effect.

WORKLOAD DATA - SUBJECTIVE WORKLOAD RATINGS

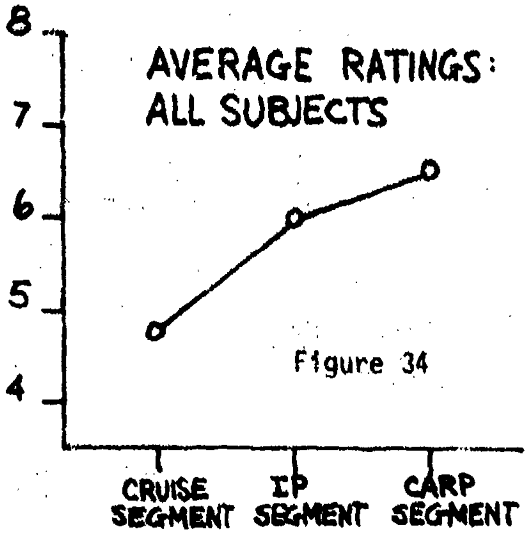


Figure 34

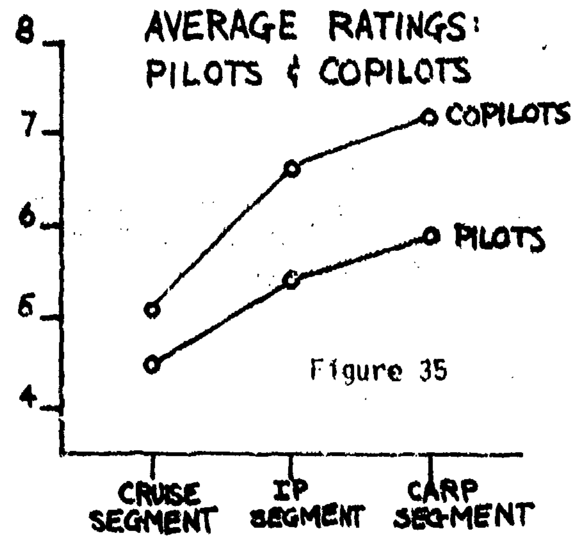


Figure 35

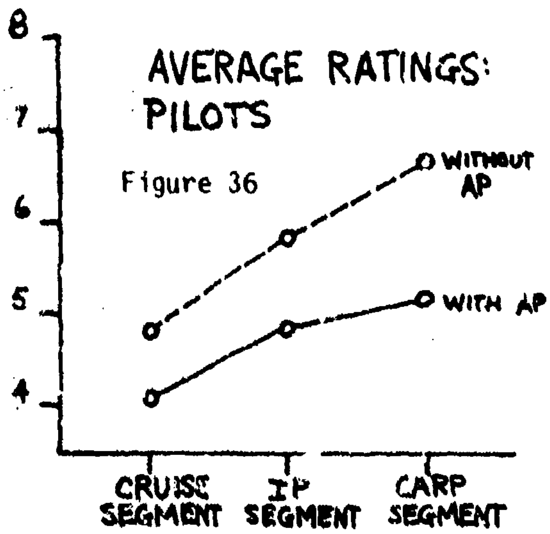


Figure 36

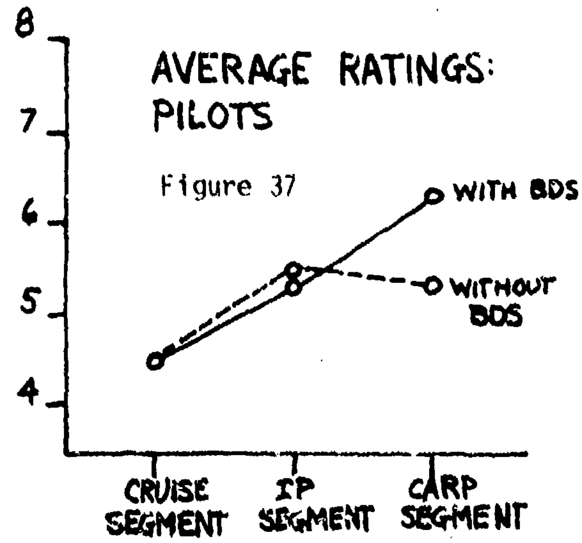


Figure 37

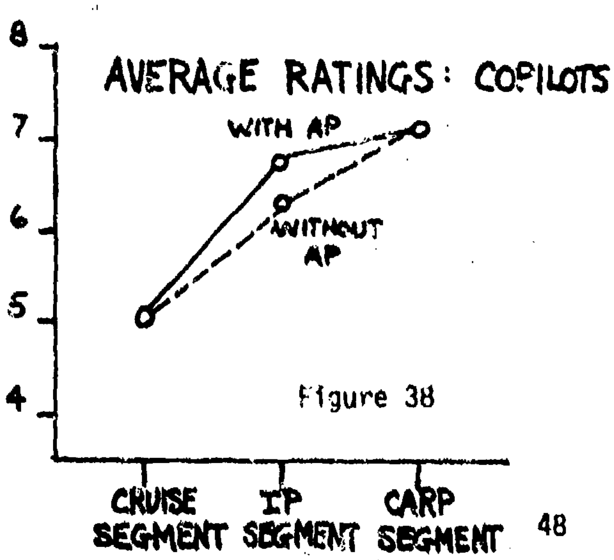


Figure 38

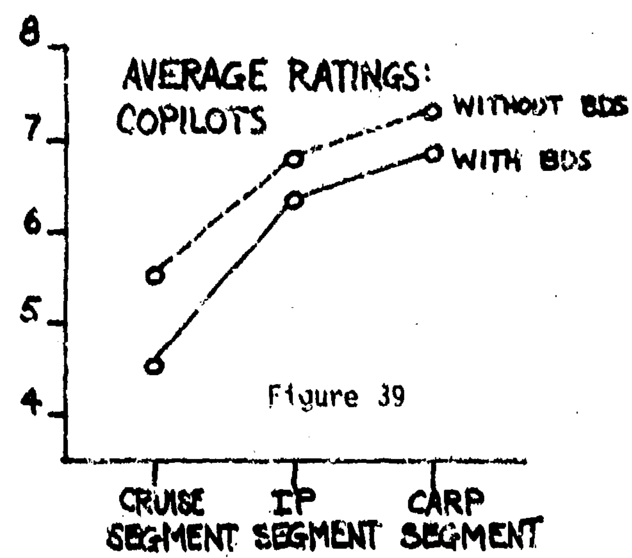


Figure 39

SUMMARY OF OBJECTIVE RESULTS

MISSION PROFILE: Several consistent trends emerge from the data which describe the subjects' performance and workload during different phases of the mission. First, there is an increase in performance accuracy (course, altitude, and airspeed) from the beginning of the flight to the drop point. Figures 18 thru 29 all illustrate this trend with the largest errors occurring during either the IP or CRUISE segments and the smallest errors occurring at the drop point. Second, the increase in performance accuracy is accompanied by an increase in workload. There is a very clear trend for the subjects' workload to increase from the beginning of the flight to the drop point. Figures 30 thru 39 illustrate this trend.

AUTOPILOT: The autopilot was effective in both improving performance accuracy and in reducing pilot workload. Figures 21 thru 24 show the effect of the autopilot on performance. Figure 36 illustrates the reduction in pilot workload. The greatest reduction in pilot workload occurs during the CARP segment when the pilot had to work harder to compensate for the lack of an autopilot.

BULK DATA STORAGE: There is evidence that the lack of bulk data storage did reduce performance accuracy during the early part of the cruise segment when the BDS related navigation task was presented (Figures 25 and 26). There is also evidence that the copilot's workload increased during the cruise segment when BDS was absent (Figure 39).

SECTION IV

DISCUSSION AND CONCLUSIONS

In considering the results of the TAWS simulation, certain aspects and constraints of the tactical transport crew system investigation should be reviewed. First, the TAWS simulation follows two previous tactical transport crew system studies accomplished in a mockup. The previous studies identified design criteria within mockup study limitations. These mockup design criteria results were tested and evaluated by the current TAWS simulation program. Second, the TAWS crew systems that were developed to meet the resulting design criteria were presented for testing and evaluation as concepts, not as hardware solutions. Third, several crew workload factors such as "see and avoid", maintaining formation position in IMC conditions and weather radar tasks were not addressed. The lack of routine aircraft system failures were also constraints of TAWS simulation.

These aspects and constraints were stressed to the subjects throughout the TAWS program to help maintain perspective and to help avoid bias in the data. However, it should be understood that some hardware compromises involving deficiencies in size, color, shape and exact location may have had some adverse but unmeasured impact on both the objective data and the conceptual evaluation of the TAWS crew systems design. Within these constraints, the TAWS simulation results are discussed.

The following discussion and conclusions are divided into two general areas of evaluation: the flight deck and the cargo compartment. Within these two areas the pilots' subjective and objective results will be discussed concerning crew complement and flight deck equipment issues. The loadmaster's subjective results will be discussed concerning crew complement and cargo compartment equipment issues.

A. Flight Deck

Issues addressed during simulated tactical transport missions were minimum crew complement and the flight deck equipment capabilities required to support a minimum crew.

CREW COMPLEMENT. The operational pilots were asked to address several crew complement issues: could a flight deck crew of two pilots fly the AMST mission as presented in the TAWS scenario; could a one loadmaster cargo crew complement fly the AMST mission with a flight deck crew of two; and if one loadmaster was inadequate, could the addition of a crew chief with some loadmaster training satisfy the minimum crew complement requirements. After flying the AMST scenario and experiencing several aerial delivery malfunctions, all of the pilots agreed that a flight deck crew of two pilots could handle the AMST mission.

However, based on equipment being flown today, most pilots felt that a single loadmaster cargo crew complement was inadequate for aerial delivery and combat offload safety and that assistance from the flight deck crew of two pilots would be a further compromise to safety. Most pilots agreed that a specially trained crew chief would be the best addition to the crew. This type of crew member could satisfy the cargo compartment safety requirements, perform several desirable flight deck duties of "see and avoid", systems monitor and assist with the checklist when he wasn't required in the cargo compartment. The crew chief type could also assume turnaround minor maintenance responsibility at austere, forward operating locations.

The objective data supported the subjective responses to the pilot crew complement issue. The pilot workload data indicated that the pilots were able to cope with the mission tasks, even though the workload increased to a high level as the flight approached the CARP.

NAVIGATION SYSTEM. In order to perform the TAWS mission a self-contained navigational system with worldwide capabilities was required. The subject pilots were tasked to apply the TAWS developed navigational concepts to the accomplishment of the AMST mission scenario. The subjective results indicate that a navigation management system capability is required for two pilots to accomplish point-to-point navigation including navigation to computed aerial release points (CARPs) to accomplish different types of aerial deliveries and navigation to austere STOL strip recoveries in adverse weather during day and night conditions. The findings also indicated that the number and type of navigation radios used in TAWS were sufficient for a jammed or non-jammed environment, i.e. 2 VOR/ILS (MLS), 1-ADF, 1-TACAN, 1-OMEGA, 1-SKE (for aerial delivery) and 2-INS.

The pilots reported that they would be able to cope with the tactical mission navigation workload if they were provided with a navigation management system capability that would increase their navigation efficiency and accuracy over that which had previously been provided by a navigator. The required navigation management system must be capable of storing, processing, displaying and automatically updating a flight plan that included an aerial delivery.

The system must also easily accept an enroute diversion and be capable of integrating ground-based navigation aid information with the INS. Display features must include flight plan information or other selected waypoint data in page (several lines of information) format versus the conventional INS single position (single line) information format. Easy system access (i.e. all purpose keyboard) by either pilot is also a requirement. Study results further indicate that required navigation displays must include: flight director information with vertical and lateral navigation position and command information; HSI alphanumeric type of waypoint identification, distance and time to waypoint; a time to target (CARP) readout; groundspeed; and drift. To further ease the pilot workload desirable features included: dual navigation management system control/displays; automatic navigation aid tuning to support

the programmed flight plan and INS update requirements; and position/progress information. Other desirable navigation information displays include: true airspeed; track; mach; and RMI waypoint identification and distance readouts. Nav system requirements imply the need for bulk data storage.

COMMUNICATIONS. The communication workload for an AMST mission can, at times, require that both pilots communicate with different agencies simultaneously. In the present study during high workload periods, such as aerial deliveries and IMC approaches, some incoming radio calls had to be ignored by the pilots due to the priority of the work being accomplished. The workload data does not specifically identify the communications task but as the data shows a workload increase there was a simultaneous increase in the communication task. Conversely, as the workload data shows a slight decrease approaching the CARP, there was a decrease in the communication task.

Most pilots felt that the number and type of communication radios provided during TAWS are sufficient to accomplish the AMST mission (i.e. 2-UHF, 1-VHF, 2-HF, 1-FM, and 1 secure voice) but that individual control heads would be too cumbersome. Also, the active communication frequency must be prominently displayed, preferably in the pilots' normal line of vision. The findings indicate that the communications system must be integrated so that tuning can be accomplished through a keyboard, which is accessible to both pilots. As an alternative method of tuning, conventional "knob" type of tuning is required for get home capability. Desired communication system features to help reduce workload were: an alerting device to indicate which radio had been selected for transmission; a standby frequency with a "active/standby" transfer capability for each communication radio; and a separate entry device for each pilot. These separate entry devices should be integrated, so that the same devices could be used for both communication and navigation entries.

AUTOPILOT. The AMST mission was flown in the TAWS program with and without the autopilot, alternating the capability at regular intervals to force the subject aircrews to address the criteria that identifies autopilot capabilities. During the present study, the copilot frequently found himself overloaded with communication and navigation tasks, so the pilot would help unload the copilot by assuming checklist duties, communication or navigation tasks. The availability of an autopilot that required minimum supervision made a large impact on how much of other flight deck duties the pilot could assume. Therefore, the subjective findings indicate a requirement for an autopilot that can be coupled to any navigation signal that is displayed on the vertical and lateral command bars of the flight director and can also be coupled to barometric altitude and selectable heading. The subjective results also identified desirable autopilot capabilities to include approach, SKE and vertical velocity coupling. An autothrottle capability was not addressed during TAWS.

The objective data showed significant support for an autopilot that can be coupled to navigation signals. This data showed that course deviations were almost non-existent when using a properly operating autopilot. Without autopilot, there were small but continual course excursions, indicating a source of pilot workload. Altitude and airspeed control were slightly better with autopilot than without, but the difference was not considered significant. Furthermore, since flight plan airspeed was seldom maintained, except for the CARP, it is assumed that autothrottles would have a considerable impact on pilot workload.

VISUAL HUD. IMC and VMC approaches and landings were accomplished as part of the TAWS full mission simulation evaluation. In order to visually acquire and maintain a desired flight path to a desired touchdown point on a short (1500') strip in a STOL configuration from a steep (6°) glide path, the subjects utilized head-up display symbology which, for TAWS was superimposed on the visual scene. The results indicate that the concept of head-up symbolic information displayed to assist in vertical guidance during visual approaches and landings to short strips is a requirement for the AMST mission. Required information on the visual HUD includes aimpoint information (flight path command bar) for vertical guidance and angle-of-attack or airspeed information to eliminate the requirement for head-down instrument panel reference during visual approaches and landings. A HUD for each pilot is considered very desirable so that the copilot can monitor the pilot's guidance information. Attitude and flare information are only moderately desirable. HUD symbology, dynamics and crew procedures were not specifically addressed and will require further study.

OTHER TAWS CREW SYSTEM DATA. A number of ancillary flight deck crew systems were addressed in the questionnaires and debriefing comments. These included:

Aerial Delivery System. This system concept, which was designed by operational crews in the field, provided required operational capabilities for pilot and loadmaster control and monitoring of aerial delivery systems and cargo compartment doors. Aerial delivery system design requirements include pilot authority over opening doors in flight and pilot authority over aerial delivery sequence and primary cargo release.

Formation Position Keeping Equipment. It should be recognized that the only portion of the SKE formation flying task that was mechanized during the TAWS program was the FCI (flight command indicator). The remaining SKE control/display components were installed for realism but were non-operational. The results of the present study indicate that the flight command indicator (FCI) must provide each pilot independent access to the FCI control/display. Due to the high pilot workload it is strongly recommended that the timing required for the initiation of SKE FCI signals and the initiation of SKE commanded maneuvers be automatically displayed to the pilots and relayed to the formation through SKE/NAV system integration; both raw (track while scan) and command SKE signals be displayed on the flight director, which would

allow pilot monitoring and autopilot coupling to SKE signals; and that the primary and secondary control units be combined and located centrally for access by either pilot. An additional suggestion for integration of information involves the simultaneous display of aircraft formation position (DVST/PPI) and weather on the same display.

Let-Down Plate Holder. The pilots found that the concept of using an approach plate holder was a necessity to help in paperwork management and to allow immediate access to written information that the pilots chose to display.

Scroll Checklist. The concept of the scroll checklist as an aid to paperwork control was considered very good. All pilots agree that the present checklist book/binder concept requires improvement in that it is very difficult to use on an AMST mission. Further design and testing is required for this issue.

Aircraft Controller. Pilot opinion concerning primary aircraft controllers indicates that the majority of subject pilots felt that a control stick provided better aircraft control authority than other controllers. However, the only controller used during the TAWS program was the yoke.

B. Cargo Compartment

During the TAWS full mission simulation, the loadmaster subject aircrews evaluated candidate cargo compartment crew system concepts while "flying" the AMST mission from a cargo compartment mockup. The crew system concepts addressed both the cargo compartment minimum crew complement issue and the systems required to support the minimum crew complement.

CREW COMPLEMENT. The loadmaster subject responses agree with the pilot responses that assistance is required for safety in the cargo compartment, especially during aerial deliveries and combat offload missions. It was generally agreed that a crew chief with some loadmaster training could fulfill the additional crew member requirement. Most loadmasters felt that improved equipment designs could alleviate the requirement for an additional crew member in the cargo compartment.

CARGO COMPARTMENT EQUIPMENT. Results indicate that future tactical transport cargo compartment crew system designs must include a forward and aft control console to allow the loadmaster to operate the cargo compartment from either station as the mission dictates. This includes a communication and radio monitoring capability and control/display to operate the cargo compartment doors, the aerial delivery system and the environment system.

COMMUNICATIONS. The subjects felt that an AIC-18 type communication system capability as presented during the present study (at fore and aft

consoles) would allow the loadmaster to monitor all necessary communication while maintaining required voice contact with the pilot. It was also suggested that an overhead communication cord trolley or a wireless intercom system be designed to provide continuous communications with the flight deck when the loadmaster duties require him to be away from the forward or aft console.

<u>OTHER SYSTEMS</u>. Subject loadmasters felt that both fore and aft consoles must provide cargo winch control and cabin lighting control to allow more operator flexibility. In addition, the forward console must provide the loadmaster supervision and control of the auxiliary power unit, cabin crew and passenger oxygen system and cabin temperature. A majority of the loadmaster subjects indicated that the forward console geometry should be improved (such as an elevated structure) to enhance the loadmaster's visual monitoring of the cargo compartment. If systems are developed to allow a single loadmaster to cope with cargo compartment emergencies (i.e. jammed or hung load, hung paratrooper, malfunctioning offload systems), the requirement for an additional crew member for safety purposes may be reduced or eliminated.

SECTION V

RECOMMENDATIONS

The following recommendations are based on an analysis of the TAWS evaluation data, addressing the primary issues of minimum crew complement and required crew system capabilities in order to perform the AMST mission.

A. Crew Complement

The conclusions drawn on the aircrew complement for the cargo compartment are based on equipment being flown today; i.e., C-130 and C-141 aircraft. New equipment could alter the findings of this study.

The minimum crew complement for the AMST mission should consist of two pilots, one loadmaster and a specially trained crew chief.

B. Nav Management System

A navigation management system capability is required which can accept a flight plan with an aerial delivery, automatically tune available navigation aids and automatically update flight plan waypoints. It must be accessible to both pilots through an all purpose keyboard and it must provide all required information previously provided by the navigator. To reduce workload, the system should allow independent information access by either pilot on independent displays. It must also provide position and command information to both pilots through independent flight directors located on the instrument panel and through other alphanumeric displays located on the instrument panel or in the normal line of sight of the pilots.

C. Communications

The communication workload demands a simple, easily accessible integrated communication system that both pilots can operate and be completely aware of how each other's radios are set up. A central tuning capability such as an all purpose keyboard entry device for each pilot has been identified as a very important design feature. An active and standby frequency readout in the pilots' normal line of vision and a backup "get home" tuning capability are also important design considerations. Capabilities required should include UHF, VHF (AM and FM) and HF.

D. Autopilot

Automatic flight control is required and must be capable of being coupled to any navigation signal displayed on the pilots' flight director command bars, and must be capable of holding an altitude and a selected heading. Autothrottles capabilities should be included in design considerations.

E. Head Up Visual Augmentation

Head up guidance information is required for both pilot and copilot. Guidance information should include flight path angle (commanded) and speed or angle of attack.

F. Aerial Delivery System

An aerial delivery system is required, with the capabilities described in this report (pg. 12).

G. Station Keeping Equipment

An improved SKE system is required. Design features must include an FCI for each pilot and an improved command/execute timing device. Auto-coupling should be a design consideration.

H. Let-Down Plate Holder

An unobtrusive lighted let-down plate holder is a required capability.

I. Cargo Compartment

A forward and an aft loadmaster's control console is required with the capabilities described on page 16.

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